California. Dept. of Water
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STATE OF CALIFORNIA
The Resources Agency
# Department of Water Resources

in cooperation with
Alameda County Water District

## BULLETIN No. 118-1

# EVALUATION OF GROUND WATER RESOURCES: SOUTH SAN FRANCISCO BAY

## Volume II: ADDITIONAL FREMONT AREA STUDY

AUGUST 1973



NORMAN B. LIVERMORE, JR.
*Secretary for Resources*
The Resources Agency

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*Governor*
State of California

WILLIAM R. GIANELLI
*Director*
Department of Water Resources

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## Volume II: ADDITIONAL FREMONT AREA STUDY

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AUGUST 1973

The Bulletin No. 118 series, which is published by the Department of Water Resources for all interested agencies and the general public, includes:

Bulletin No. 118-1 <u>Evaluation of Ground Water Resources: South Bay</u>

Appendix A: Geology, August 1967

Volume I: Fremont Study Area, August 1968

Volume II: Additional Fremont Area Study,

Volume III: North Santa Clara County (now under study)

Bulletin No. 118-2 <u>Evaluation of Ground Water Resources: Livermore and Sunol Valleys</u> (now under study)

Appendix A: Geology, August 1966

After completion of the evaluation studies, operations-economics studies of each ground water basin or study area will be scheduled and conducted cooperatively with local agencies.

## FOREWORD

The South Bay Ground Water Basin underlies south San Francisco Bay and the gently sloping lands adjacent to the Bay in Alameda, San Mateo, and Santa Clara counties. The ground water basin is divided into three main units: the Fremont study area, containing the Bay and southern Alameda County; the Santa Clara study area to the south; and the San Mateo study area to the west.

In the Fremont study area, extractions exceeded recharge for many years, resulting in extensive salt water intrusion of the ground water aquifers. The Alameda County Water District has countered the salt water intrusion by augmenting the ground water supplies of the Fremont study area with imported water supplies from the South Bay Aqueduct of the State Water Project and the City of San Francisco's Sunol Aqueduct. Withdrawals from the basin were also reduced by using imported water from the Hetch Hetchy Aqueduct.

This report is a supplement to Bulletin No. 118-1, "Evaluation of Ground Water Resources, South Bay, Volume I: Fremont Study Area", published in August 1968. The report presents the results of additional studies by the Department in cooperation with the Alameda County Water District, contains additional detailed geology of the area, and presents an accounting of recharge to and withdrawals from the ground water basin for the period October 1961 through September 1970.

During the period studied, actions of the local operating agency have resulted in a recovery of water levels in the ground water basin. However, the basin is still endangered by saline intrusion and preliminary design of a salt water barrier should be completed and construction started promptly. The conceptual plan for a salt water barrier is described in this report. Detailed planning for the barrier and testing of materials to be used for construction of the barrier are continuing as part of the cooperative study by the Department and the Alameda County Water District.

William R. Gianelli

William R. Gianelli, Director
Department of Water Resources
The Resources Agency
State of California
July 25, 1973

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## ACKNOWLEDGMENT

For the cooperation rendered by Alameda County Flood Control and Water Conservation District, Leslie Salt Company, and the cities of Fremont, Newark, and Union City, in permitting installation of test facilities, the Department of Water Resources is deeply grateful.

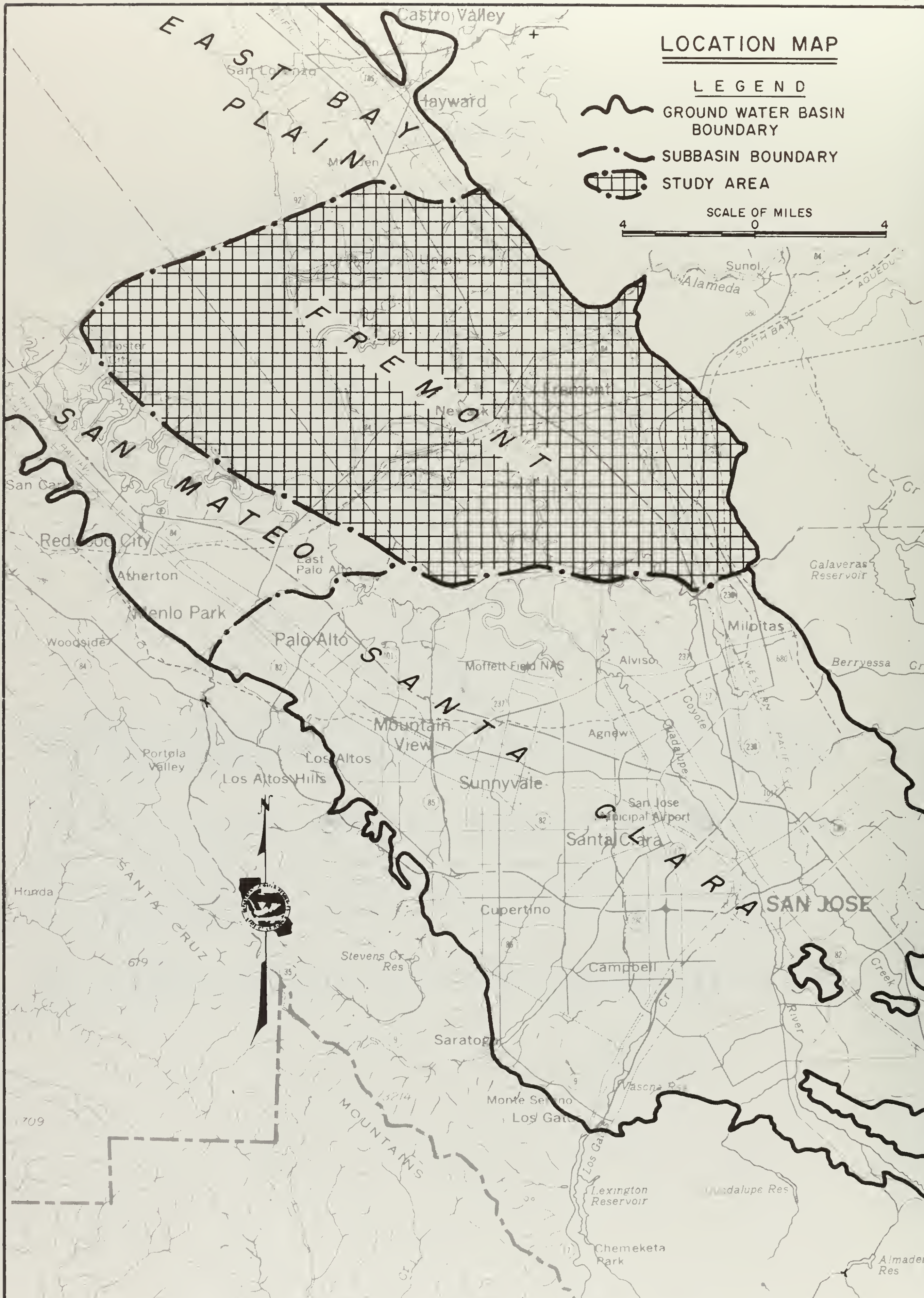

## ABSTRACT


The Fremont study area is located in southwestern Alameda County and occupies the northwestern portion of the South San Francisco Bay ground water basin. From the 1920's to the present, saline water intrusion has been a problem in the area. The utility of the ground water reservoir has been preserved by the Alameda County Water District through the construction and operation of recharge facilities and the importation of water purchased from the State of California (State Water Project) and the City of San Francisco (Hetch Hetchy System).

Detailed geologic and hydrologic studies of the Fremont area were made in the 1960's and the results published in two Department reports: Bulletin No. 118-1, "Evaluation of Ground Water Resources, South Bay, Volume I: Fremont Study Area", August 1968; and Appendix A, "Geology", August 1967.

This report contains the results of a cooperative study by the Department and the Alameda County Water District of geologic and hydrologic conditions affecting the occurrence and movement of ground water, the relation between recharge to and withdrawals from the ground water system, and methods of controlling sea water intrusion.

The study concludes that although the amount of ground water in storage had significantly increased during the 1961-71 decade, sea water intrusion is still a serious threat to the ground water basin. The report presents a conceptual plan for a sea water intrusion barrier and recommends rapid completion of its design and installation.


LOCATION MAP
LEGEND
GROUND WATER BASIN BOUNDARY
SUBBASIN BOUNDARY
STUDY AREA
SCALE OF MILES
4 0 4
EAST BAY PLAIN
FREMONT
SAN MATEO
SANTA CLARA
Castro Valley
San Lorenzo
Hayward
Fremont
Newark
Sunol
Alameda
Calaveras Reservoir
Redwood City
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Saratoga
Monte Sereno
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Vasona Res
Lexington Reservoir
Chemeketa Park
Almaden Res
SANTA CRUZ MOUNTAINS
Creek
River

## CHAPTER I. SUMMARY, FINDINGS AND RECOMMENDATIONS

The Fremont study area, shown on Figure 1, is located in southwestern Alameda County and occupies the northeastern portion of the South San Francisco Bay ground water basin. From the 1920's to the present, saline water intrusion has been a problem in the area. The utility of the ground water reservoir has been preserved by the Alameda County Water District through the construction and operation of recharge facilities and the importation of water purchased from the State of California (State Water Project) and the City of San Francisco (Hetch Hetchy System).

### Study Objectives

Detailed geologic and hydrologic studies of the Fremont area were made in the 1960's and the results published in two Department reports: Bulletin No. 118-1, "Evaluation of Ground Water Resources, South Bay, Volume I: Fremont Study Area", August 1968; and Appendix A, "Geology", August 1967. In June 1968, the Department and the Alameda County Water District entered into an agreement to study the ground water resource on a cooperative basis. The objectives of the study were:

1. Modification of the District's data collection program to provide greater areal coverage and increased reliability of data.

2. Further definition of the subsurface geology and hydrology of the ground water basin based on additional data obtained from the modification of data collection networks, drilling of test holes and pump testing.

3. Review of alternative methods of controlling saline water intrusion and the development of preliminary plans and costs for a proposed saline water barrier.

4. Development of criteria for use and operation of artificial recharge facilities.

### Study Results

The cooperative study during the 1968-72 period has accomplished these objectives with the exception of the fourth, relating to the operation of the recharge facilities. The continuing construction of the new Alameda Creek flood control channel through the recharge facilities has forced this portion to be postponed, although the ground water model being developed during the study will assist in determining operational plans for the recharge facilities.

Modifications in the District's data collection program have been made during the study to take advantage of the more detailed information on the hydrology and subsurface geology of the ground water basin. The data collection program now

records changes in ground water levels and quality for each of the several aquifers and has been expanded to cover the entire study area.

The result of the geologic study is a detailed mapping of the subsurface channels of Alameda Creek and adjacent streams, and is presented in Chapter II as an extension of information presented in Volume I and Appendix A of Bulletin 118-1. The detailed mapping was accomplished by a new approach, utilizing computer methods to evaluate subsurface geologic data. This work is significant in that it provides the basis for the location and design of an efficient salinity barrier, and indicates that the subsurface flow of water is highly directional, an important input for the successful modeling of the basin. The model of the basin will be used in planning the salinity barrier. Understanding the separate roles played by aquifers and by aquitards in the ground water system is a necessary preliminary to controlling saline water intrusion. Aquifer and aquitard characteristics are described in Chapters II and III. Each of these can be defined as:

> Aquifer - A porous, water-bearing geologic formation. Generally restricted to materials capable of yielding an appreciable supply of water.
>
> Aquitard - A geologic formation which, although porous and capable of absorbing water slowly, will not transmit it rapidly enough to furnish an appreciable supply for a well or spring. The permeability is so low that for all practical purposes, water movement is severely restricted. When separating extensive aquifers having a large head differential between them, it acts as a confining bed but the total water movement may be significant even though water movement per acre is insignificant.

The results of the hydrologic studies are presented in Chapter IV as the status of saline water intrusion, and in Chapter V as an extension of the ground water inventory contained in Bulletin 118-1, Volume I, August 1968.

Review of alternative ways of controlling sea water intrusion indicated that a series of shallow pumping wells placed in the center of the subsurface channels defined in the geologic study could intercept saline water flowing into the basin and at the same time establish a bayward gradient in the intruded upper aquifer. This type of plan, called a pumping trough barrier, has been adopted as a basic plan. The preliminary location for the barrier reported on in Chapter IV uses the Coyote Hills as the central section and the eastern limits of the salt evaporation ponds as the north and south sections. As part of the continuing study, the District and Department have installed and tested one experimental well and are in the process of designing a second installation. Both agencies plan to continue developing a workable barrier design as rapidly as possible.

## Findings

During the decade 1961-71, the amount of ground water in storage has been significantly increased by over 60,000 acre-feet and water levels have recovered approximately 55 feet in the forebay adjacent to the upper portion of Alameda Creek. During the same period average pumpage for beneficial uses has remained at approximately 40,000 acre-feet per year. Operation of gravel quarries during

the last three years of the study period involved pumping to lower water levels in the quarries. The water pumped by the quarries was wasted to San Francisco Bay. This practice was stopped in May 1971 by a Superior Court injunction obtained by the Alameda County Water District. The improvement in the ground water situation is primarily due to the importation and recharge by the Water District of large amounts of water through the State Water Project's South Bay Aqueduct.

The Alameda County Water District has plans to reduce the total pumpage for conventional uses from the basin for the next five years. An 8.0 million gallons per day water treatment plant to treat South Bay Aqueduct water for the District's distribution system is scheduled for completion in 1974, and this plant will be operated to reduce the District's pumping.

The District's full recharge capability has been used to meet pumping demands and to refill the ground water basin. By late 1972 the piezometric surface of the upper aquifer was at sea level. Recharge capability in excess of the requirements to maintain this level in the upper aquifer will be used to replace saline water that the District plans to pump from the basin. These plans are to pump saline water that is trapped in the Centerville, Fremont and deep aquifers into San Francisco Bay. If this saline water is not removed, it will spread to the usable parts of these aquifers and thus render them unusable.

It is important to complete preliminary design of a sea water barrier and to begin construction of a barrier. There are three compelling reasons for prompt action: (1) any decrease in the supply to or the operation of the recharge facilities can cause large amounts of salt water to intrude the basin; (2) uncontrolled migration of saline water from the upper intruded aquifer to the lower producing aquifers will continue to lessen the utility of the entire basin (initial operation of the barrier would withdraw saline water from the upper aquifer); and (3) the necessarily long construction time required to complete the barrier.

## Recommendations

It is recommended that the planning of the sea water intrusion barrier and development and testing of prototype barrier wells, which are part of the current Department-District study, be completed as soon as possible so that the District can make a decision on starting a long range barrier construction program as rapidly as possible. Barrier wells should be designed and installed one or two at a time, tested, and results used to improve design of the next series of wells.

# CHAPTER II. AQUIFER CHARACTERISTICS

The identification of horizontal and vertical boundaries of aquifers and aquitards is extremely difficult in most alluvial-filled valleys of California. In the past, this identification has been accomplished only on a gross scale and has been derived through the construction of geologic sections using drillers' logs of water wells as well as electric logs of oil and gas wells. Using this method, generalized formational boundaries and member boundaries can usually be determined. The subsurface data presented in Volume I of Bulletin 118-1, August 1968, and in Appendix A, August 1967, of that volume were derived in this manner.

This method of analysis does not provide the degree of detail that is required for operational studies of some ground water basins, particularly those in which older buried stream channels provide the media through which the major portion of ground water moves. Consequently, a new approach utilizing computer methods was developed to determine the continuity of the various aquifer systems present in the Fremont study area. In this approach, use was made of the now buried depositional patterns which make up the Niles Cone. In the construction of a depositional feature such as the Niles Cone, the contributing stream (in this case Alameda Creek) has meandered back and forth across the up to 12-mile width of the cone, depositing stream-borne materials which range in size from coarse gravel and boulders down to clay. During periods of normal runoff, a stream course is established which contains the coarsest grained materials. These materials grade from large gravels and boulders at the apex of the cone to sand and silt at its distal end. Adjacent to the stream channel are clays and silts which grade outward to even finer grained materials. Periodically, during periods of storm runoff, the stream will abandon its course and seek a new route down the surface of the fan. It also may meander over short distances of less than a thousand feet, thus forming braided channel deposits. In time, as deposition continues, the abandoned stream channels become covered with younger materials. These materials usually are fine grained, thus isolating the old stream channel and converting it into a tabular aquifer. In a few cases, younger stream channels may form along or across older channels, thus creating areas of hydraulic continuity between different channel deposits. In a few cases, the older, buried channels may subsequently become warped or cut off due to regional tilting or faulting.

## Computer Assisted Subsurface Geologic Evaluation

In the Fremont study area, a special computer program was developed to utilize information on the subsurface materials derived principally from logs of water wells. In analyzing these logs, it was found that the "calls" used by various drillers differed for the same material. It also was found that drillers' calls may be grouped, and thus a statistical analysis may be made based on these calls. This same approach was used by the U. S. Geological Survey, which grouped the drillers' calls by specific yield values in its study of the San Joaquin Valley. This grouping of calls, modified for the Fremont study area, is

presented on Table 1. The steps in the geologic analysis which utilized this grouping are briefly described below.

1. The deepest well per quarter-quarter section (a one-quarter mile spacing) in the study area was identified and the values of the equivalent specific yield (ESY) tabulated for each material reported on the log. Equivalent specific yield is defined as being equal to the specific yield of a given material under unconfined conditions. The ESY of a material is a pure number and remains the same whether the material is presently under confined or unconfined conditions, as it relates to the relative grain size and not to the quantity of ground water which could be derived from it.

2. The ESY values were averaged for 10-foot increments of elevation for each well used.

3. The averaged ESY values were then converted to symbolic form for utilization in graphic presentation. Four symbols were used which represent the main types of depositional material:

| Symbol | Range of ESY Values | Typical Material |
|---|---|---|
| . | 1 to 7 | Clay, Bay Mud, Silt |
| - | 8 to 12 | Clay with Fine Sand |
| + | 13 to 17 | Sand with Clay Streaks |
| 0 | 18 to 25 | Gravel, Coarse Sand |

4. Using a computer program, the symbolic ESY values were printed out areally for each 10-foot increment of elevation at a horizontal scale of 1-inch equals 4,000 feet. Each of these "maps" were then printed on transparent media and prepared for viewing and analysis.

5. Geologic interpretation of the several maps was then made by stacking them in ascending order of elevation. In this case, maps of the Fremont area were made for the intervals of -550 to -540 feet up to +190 to +200 feet. By viewing the maps from above, the traces of the buried stream channels could be seen meandering down through the various levels. Also, areas of fine grained material could be identified as well as zones of hydraulic continuity between various levels.

6. It was recognized that several layers of clay, or aquitards, exist in the Fremont area, and it is believed that much of this material was deposited during times of a higher sea level. Thus it was concluded that zones of aqueously deposited clay could be identified and traced, as these clays are predominantly colored blue, green, or gray due to the reduced state of the iron present in the clays. In contrast, terrestrially deposited clays tend to contain iron in an oxidized state and thus are colored yellow, brown, or red.

TABLE 1

SPECIFIC YIELD VALUES
FOR DRILLERS CALLS

| General Material Type and Specific Type | Drillers Calls | | |
|---|---|---|---|
| Crystalline Bedrock Specific Yield = 00 Percent | Granite | Hard Rock | |
| | Lava | Rock | |
| Clay and Shale Specific Yield = 03 Percent | Adobe | Granite Clay | Shale |
| | Boulders in Clay | Hard Clay | Shaley Clay |
| | Cemented Clay | Hard Pan | Shell Rock |
| | Clay | Hard Sandy Shale | Silty Clay Loam |
| | Clayey Loam | Hard Shell | Soapstone |
| | Decomposed Shale | Muck | Smearey Clay |
| | | Mud | Sticky Clay |
| Clayey Sand and Silt Specific Yield = 05 Percent | Chalk Rock | Peat | Sandy Clay |
| | Clay and Gravel | Peat and Sand | Sandy Silt |
| | Clayey Sand | Pumice Stone | Sediment |
| | Clayey Silt | Rotten Conglomerate | Shaley Gravel |
| | Conglomerate | Rotten Granite | Silt |
| | Decomposed Granite | Sand and Clay | Silty Clay |
| | Gravelly Clay | Sand and Silt | Silty Loam |
| | Lava Clay | Sand Rock | Silty Sand |
| | Loam | Sandstone | Soil |
| Cemented or Tight Sand or Gravel Specific Yield = 10 Percent | Arcade Sand | Cemented Sand | Hard Sand |
| | Black | Cemented Sand and Gravel | Heavy Rocks |
| | Blue Sand | Dead Gravel | Lava Sand |
| | Caliche | Dead Sand | Soft Sandstone |
| | Cemented Boulders | Dirty Pack Sand | Tight Boulders |
| | Cemented Gravel | Hard Gravel | Tight Coarse Gravel |
| | | | Tight Sand |
| Gravel and Boulders Specific Yield = 15 Percent | Cobbles and Gravel | Gravel and Boulders | Rocks |
| | Coarse Gravel | Heaving Gravel | Sand & Gravel, Silty |
| | Boulders | Heavy Gravel | Tight Fine Gravel |
| | Broken Rocks | Large Gravel | Tight Medium Gravel |
| | | | Muddy Sand |
| Fine Sand Specific Yield = 15 Percent | Fine Sand | Quicksand | Sand, Gravel, and Boulders |
| Sand and Gravel Specific Yield = 20 Percent | Dry Gravel | Gravelly | Sand and Gravel |
| | Loose Gravel | Gravelly Sand | Sand |
| | | Medium Gravel | Water Gravel |
| Coarse Sand and Fine Gravel Specific Yield = 25 Percent | Coarse Sand | Fine Gravel | Medium Sand |
| | | | Sand and Pea Gravel |

Based on Geological Survey Water Supply Paper 1469, "Ground Water Conditions and Storage Capacity in the San Joaquin Valley, California", 1959.

A separate computer program using the same well logs was developed to separate reduced and oxidized clays. The color of the materials was noted for each elevation increment and this information was put into a computer program which printed out the percent of reduced clay, ranging from 0 for a 10-foot thickness of oxidized clay to 99 for a like thickness of reduced clay. Using these data in conjunction with the ESY data, it was found that certain zones of the fine grained materials were composed principally of reduced clay and thus probably were deposited subaqueously. Because of this, it may be assumed that the subaqueous clays are fairly continuous and serve as aquitards.

Geologic sections which were prepared from well logs and the area printouts are presented as Figure 2. Figure 3 presents configurations of aquifer and aquitard materials at selected elevation intervals. Examination of the various maps and sections will show that the Fremont study area is roughly divisible into several aquifer zones and aquitards. From the ground surface downward, these zones, which are indicated on the geologic sections, are: Newark Aquitard, Newark Aquifer, Irvington Aquitard, Centerville Aquifer, Mission Aquitard, and Fremont Aquifer.

For interpretative purpose, materials have been separated into aquifer and aquitard groups on the basis of having average specific yield values of under or over 7 percent. The transmissibility of the aquifer materials increases generally with increasing specific yield, with a low transmissibility rate for specific yields near 8 percent.

Interpretation of the data uses average values for 10-foot elevation increments. As a result, the geologic sections may show aquifer or aquitard materials to be five feet thicker or thinner than the actual thickness. Surface exposures of aquifer material shown in the geologic sections should be interpreted as meaning that aquifer materials are present in the first ten feet of depth. This does not however, preclude the existence of extensive clay deposits of up to approximately seven feet thickness. In addition, the grain size of aquifer materials becomes finer with increased distance from the apex of the alluvial fan formed by Alameda Creek. This fan, called the Niles Cone, is the major physiographic feature of the Bay Plain portion of the Fremont study area. All of the aquifers and aquitards in this area are present as beds within this cone, as most of the materials were either derived from deposition by Alameda Creek or were influenced by it.

## Sequences of Aquifers and Aquitards

The Newark aquitard is exposed at the ground surface throughout much of the Fremont area. This is the "clay cap" that is commonly spoken of by the various well drillers. The aquitard is composed of a mixture of fine material deposited subaqueously and on land, slopes gently bayward, and is expressed on Sheets 1 and 2 of Figure 3 as the open area southwest, west, and northwest of the large area of aquifer material near Niles. Because some of the aquitard was transected by stream channels, several isolated bands of channel deposits are shown crossing it.

Lying immediately below the Newark aquitard is the Newark aquifer, which shows its greatest expression on Sheet 3 of Figure 3, in the elevation interval -30 to -40 feet. Subsurface relationships of this aquifer are shown in the geologic

sections on Figure 2. A minimum of aquifer material is shown on Sheet 6 of Figure 3, representing the elevation interval of -120 to -130 feet. This is inferred to be the main zone of the Irvington Aquitard in the eastern portion of the Niles Cone, increasing in thickness to an interval of -120 to -160 feet in the portion of the Niles Cone southeasterly and northerly of the Coyote Hills. The eastern portion of the clay zone also contains stringers of channel material. The clay zone westerly of the Coyote Hills is primarily subaqueously deposited fine material. Below the Irvington Aquitard is the Centerville Aquifer which is depicted on the geologic sections shown in Figure 2. It attains its greatest expression in the interval from -180 to -190 feet, as shown on Sheet 8 of Figure 3.

Of major importance to the understanding of salt water intrusion and its control, are the locations of the subsurface channels connecting the Newark Aquifer with lands underlying the salt evaporation ponds and South San Francisco Bay. The locations of the subsurface channels connecting the various aquifers with the main recharge areas is important in planning recharge programs and in selecting well locations. The axes of the subsurface channels between elevations +30 and -70 are shown on Figure 3, Sheets 1-4.

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| F-5, F-6 | 4 |
| F-7 | 5 |


**LEGEND**

AQUIFER (MATERIALS HAVING SPECIFIC YIELDS GREATER THAN 7 PERCENT)

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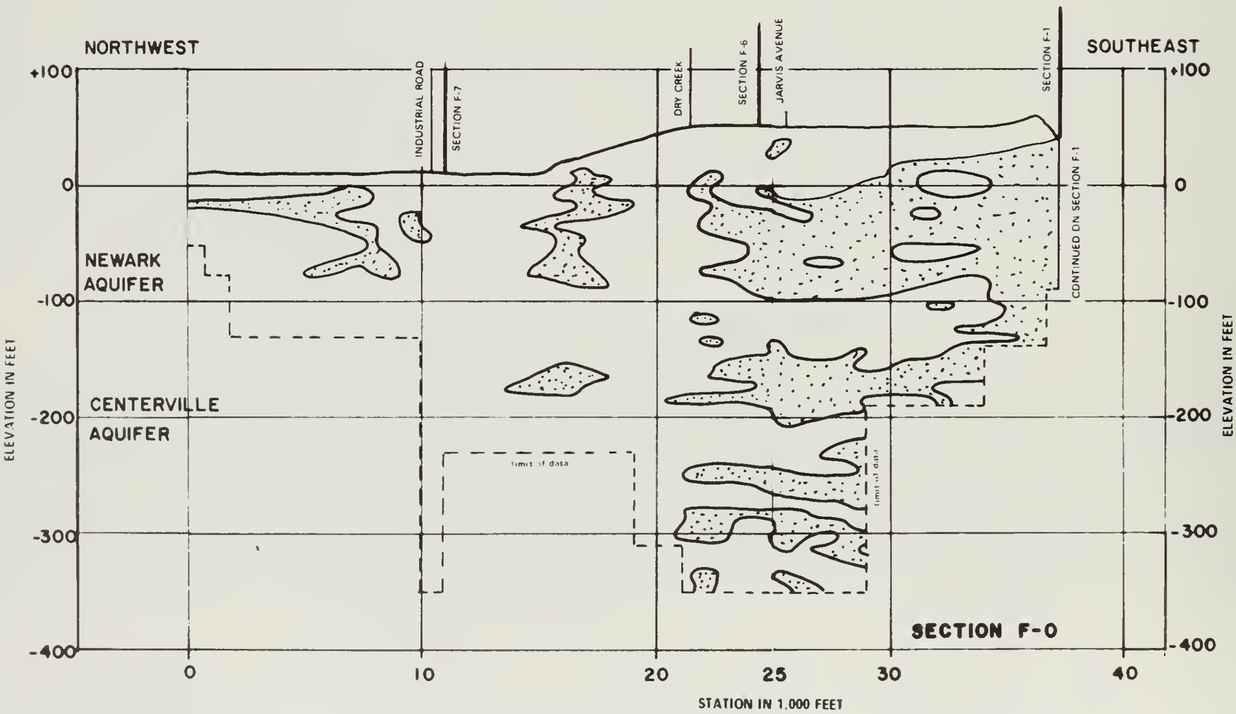
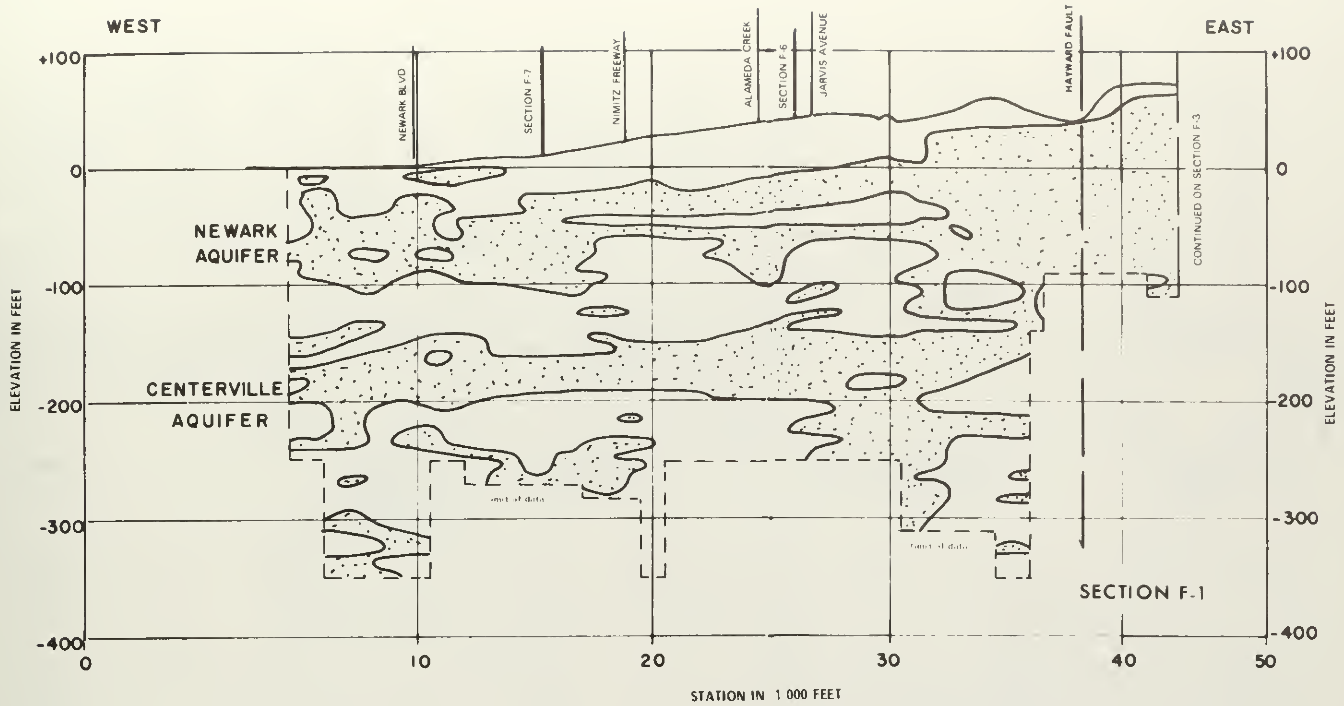



FIGURE 2 — GEOLOGIC SECTIONS




**LEGEND**

AQUIFER (MATERIALS HAVING SPECIFIC YIELDS GREATER THAN 7 PERCENT)

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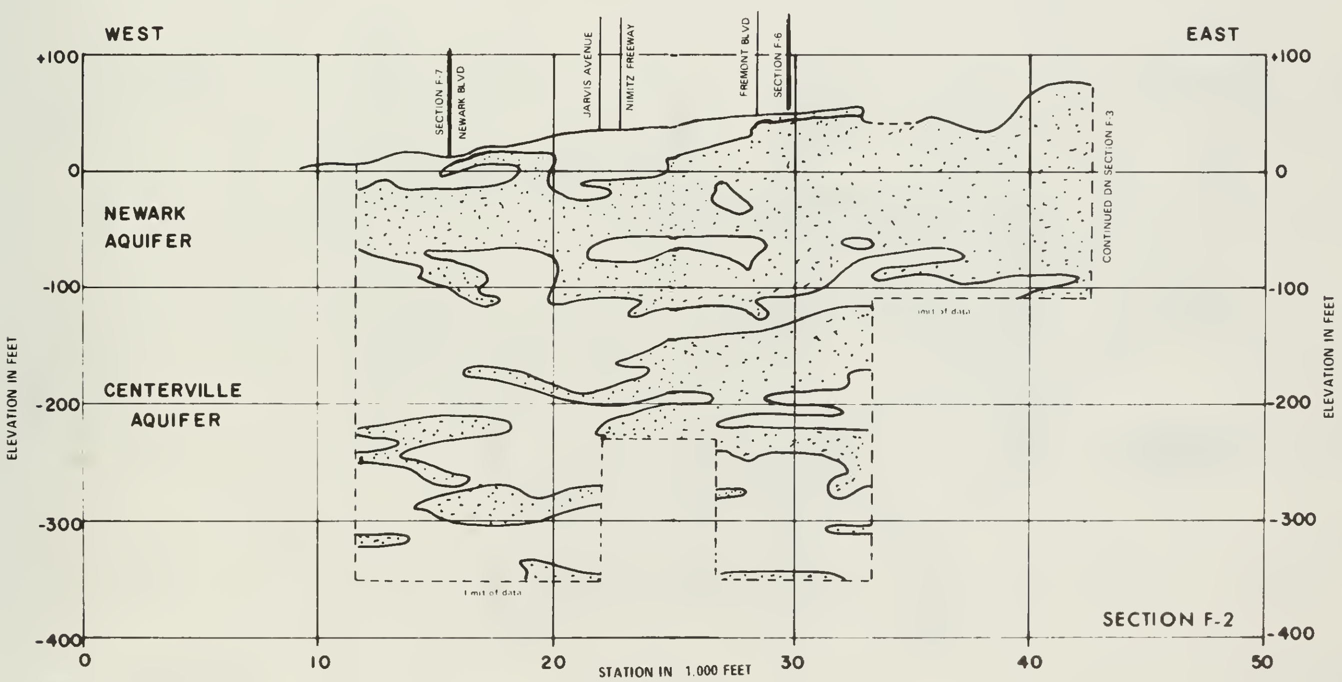
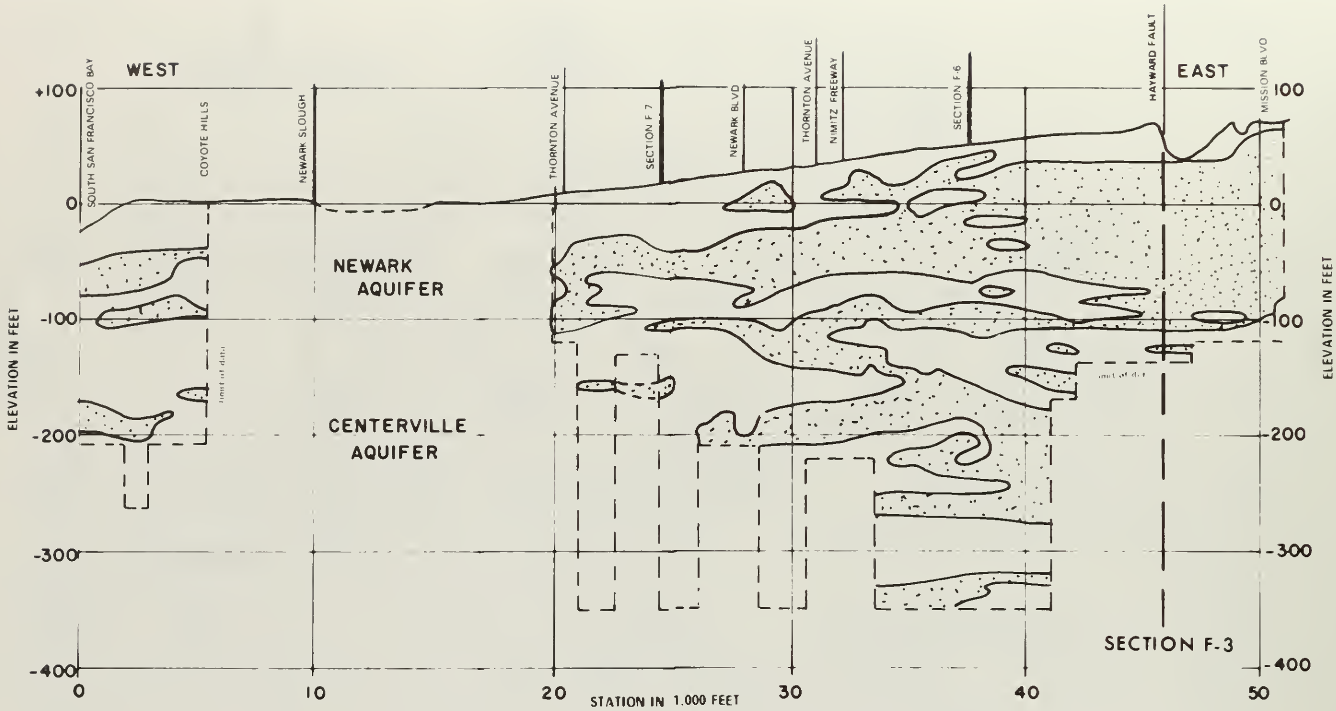



FIGURE 2 — GEOLOGIC SECTIONS

SHEET 2 of 5



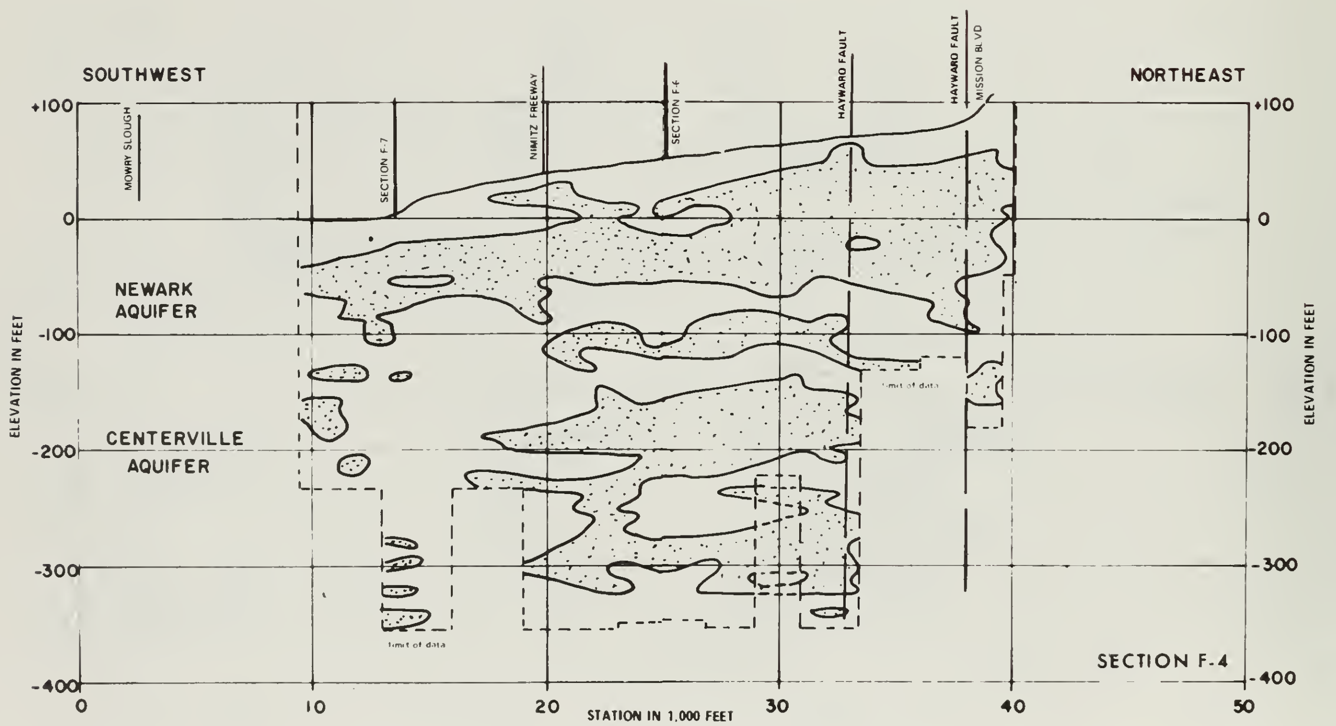
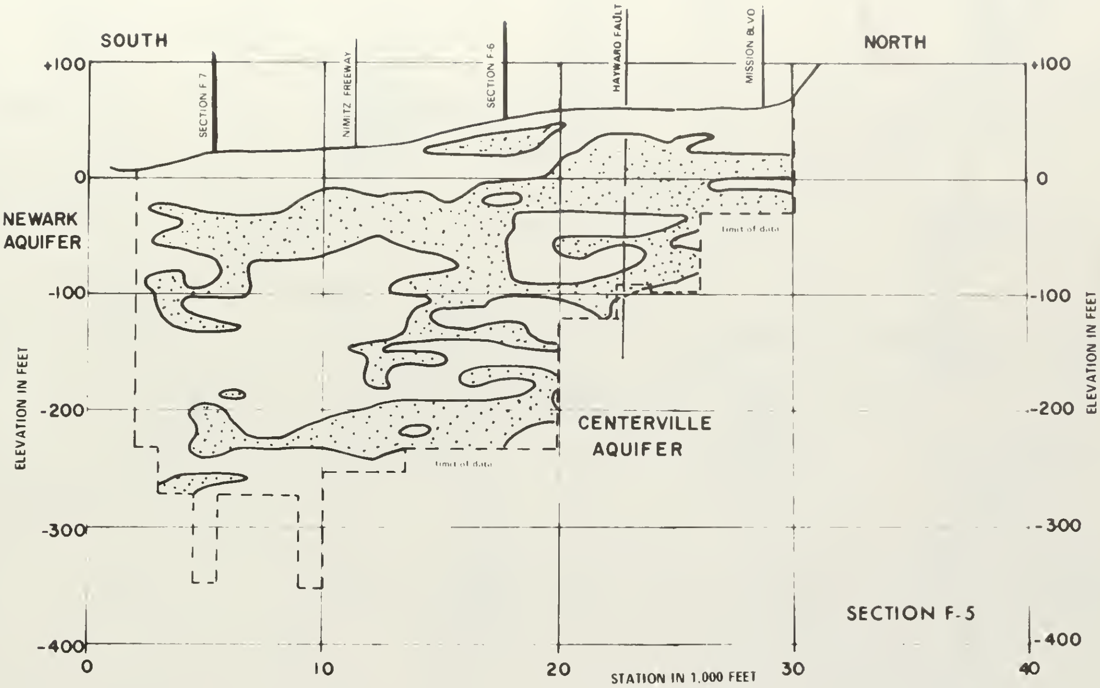




FIGURE 2 - GEOLOGIC SECTIONS SHEET 3 of 5



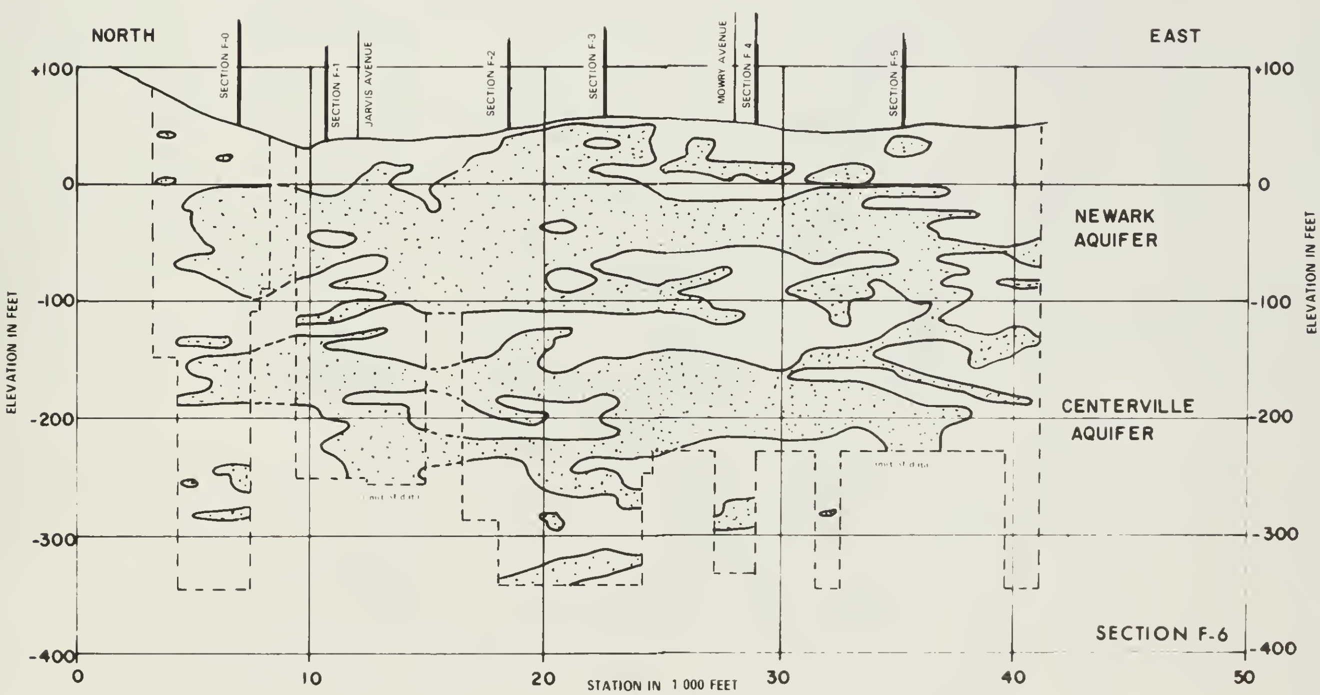
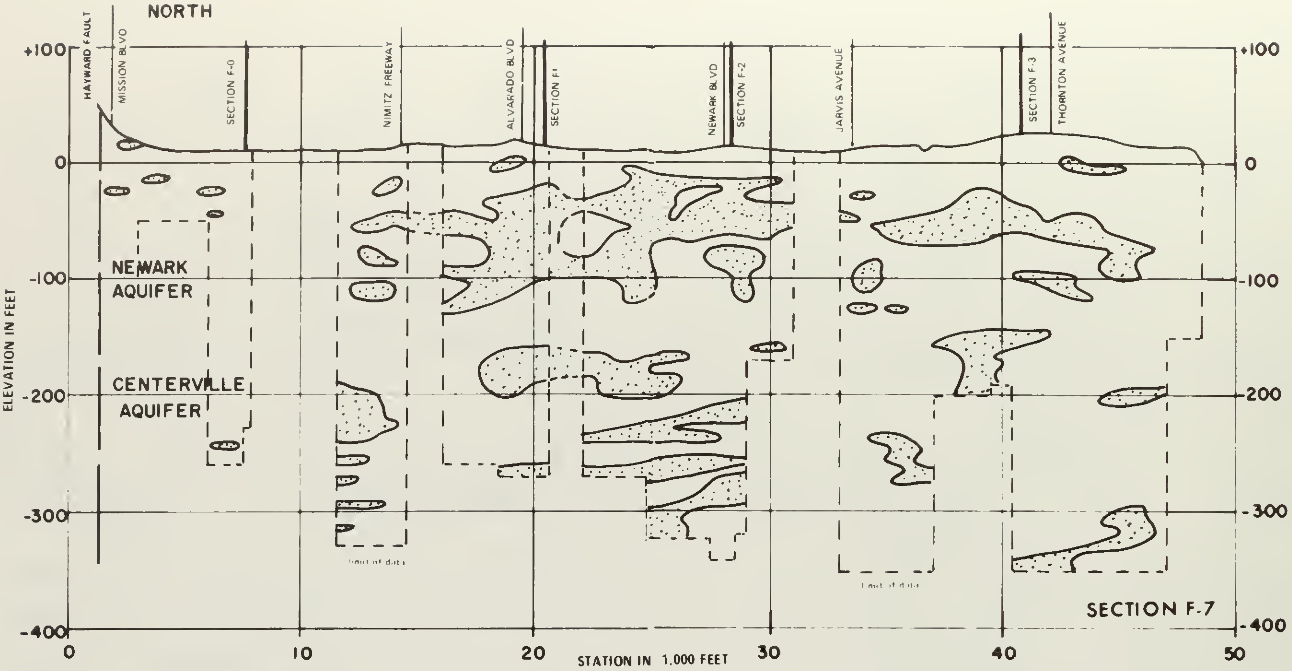




FIGURE 2 – GEOLOGIC SECTIONS SHEET 4 of 5



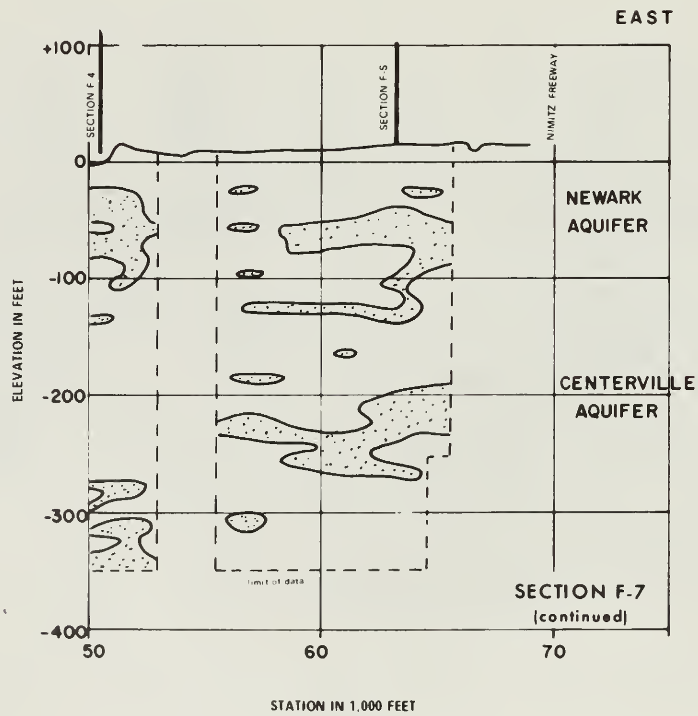




FIGURE 2 - GEOLOGIC SECTIONS SHEET 5 of 5

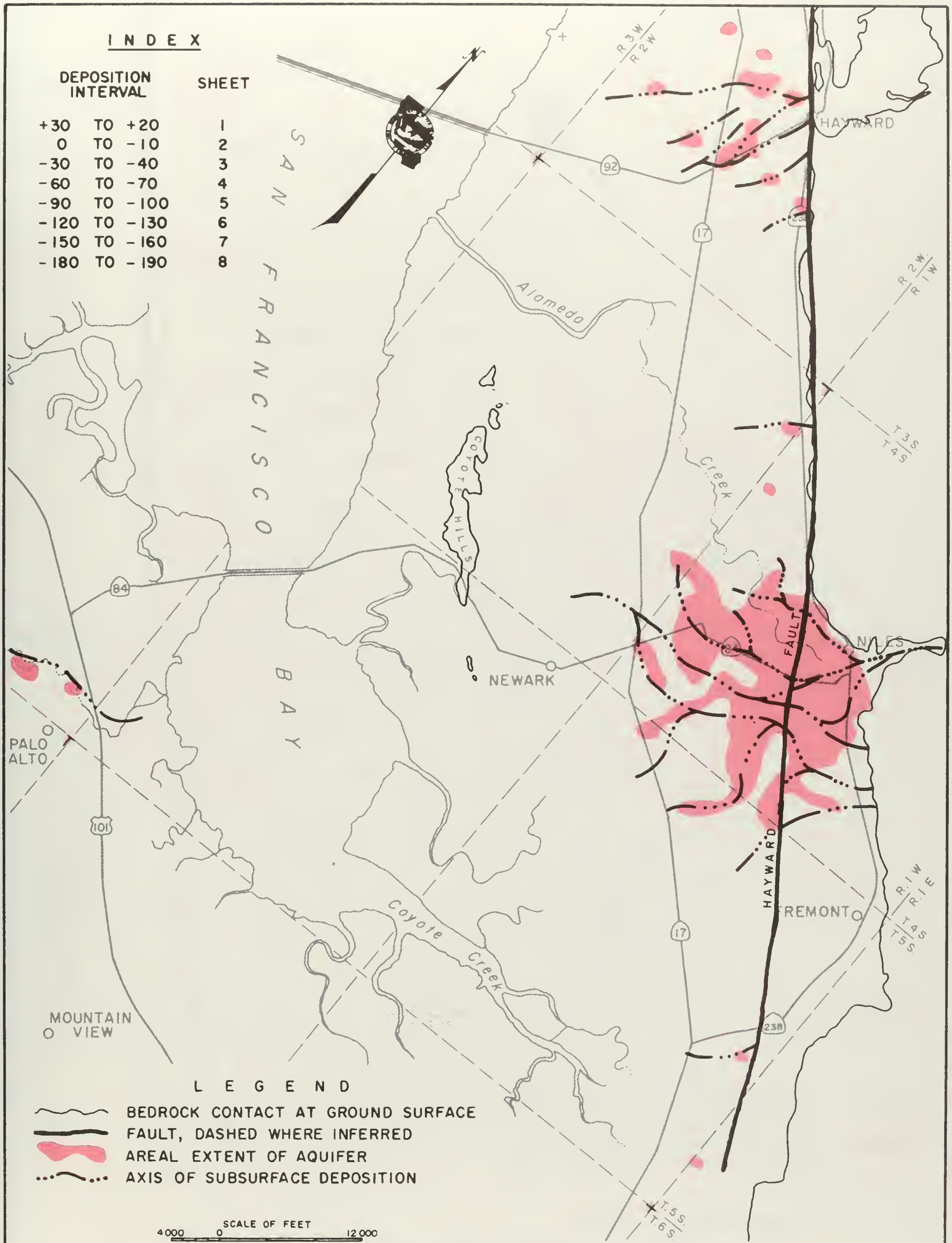



Figure 3. SUBSURFACE DEPOSITIONAL PATTERNS
SHEET 1 OF 8 ELEVATION INTERVAL +30 FEET TO +20 FEET

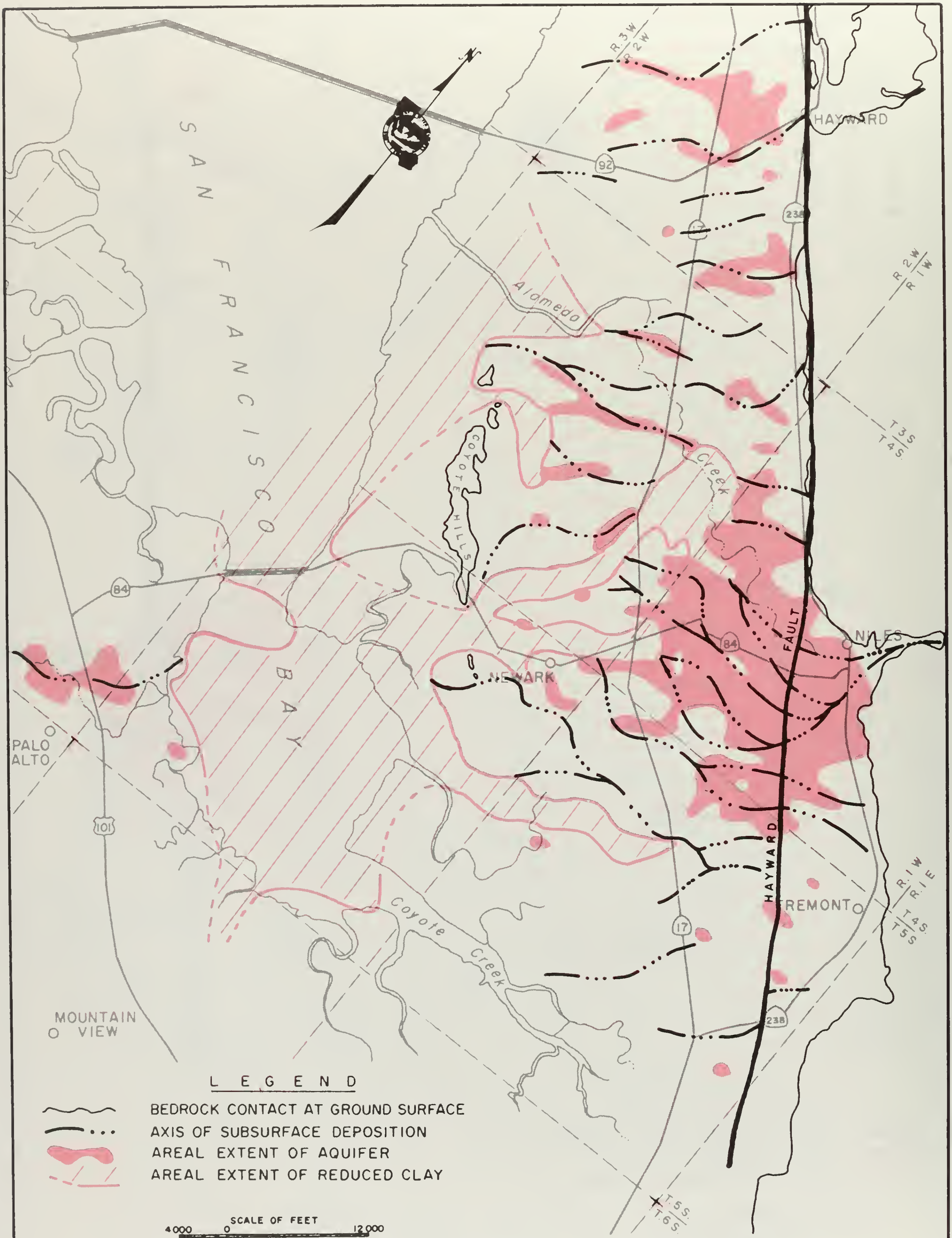



Figure 3. SUBSURFACE DEPOSITIONAL PATTERNS
SHEET 2 OF 8 ELEVATION INTERVAL 0 FEET TO -10 FEET

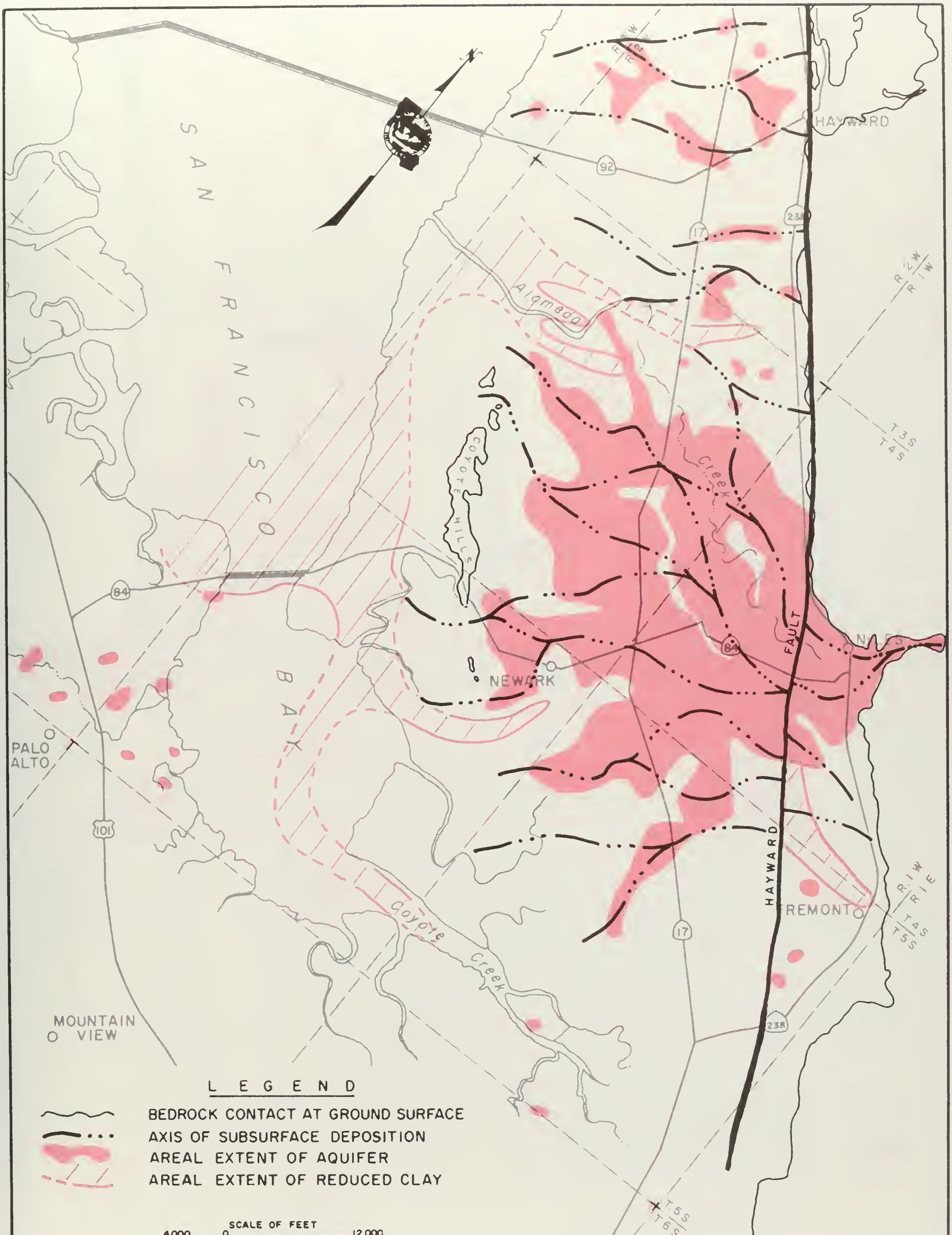



Figure 3. SUBSURFACE DEPOSITIONAL PATTERNS
SHEET 3 OF 8 ELEVATION INTERVAL -30 FEET TO -40 FEET

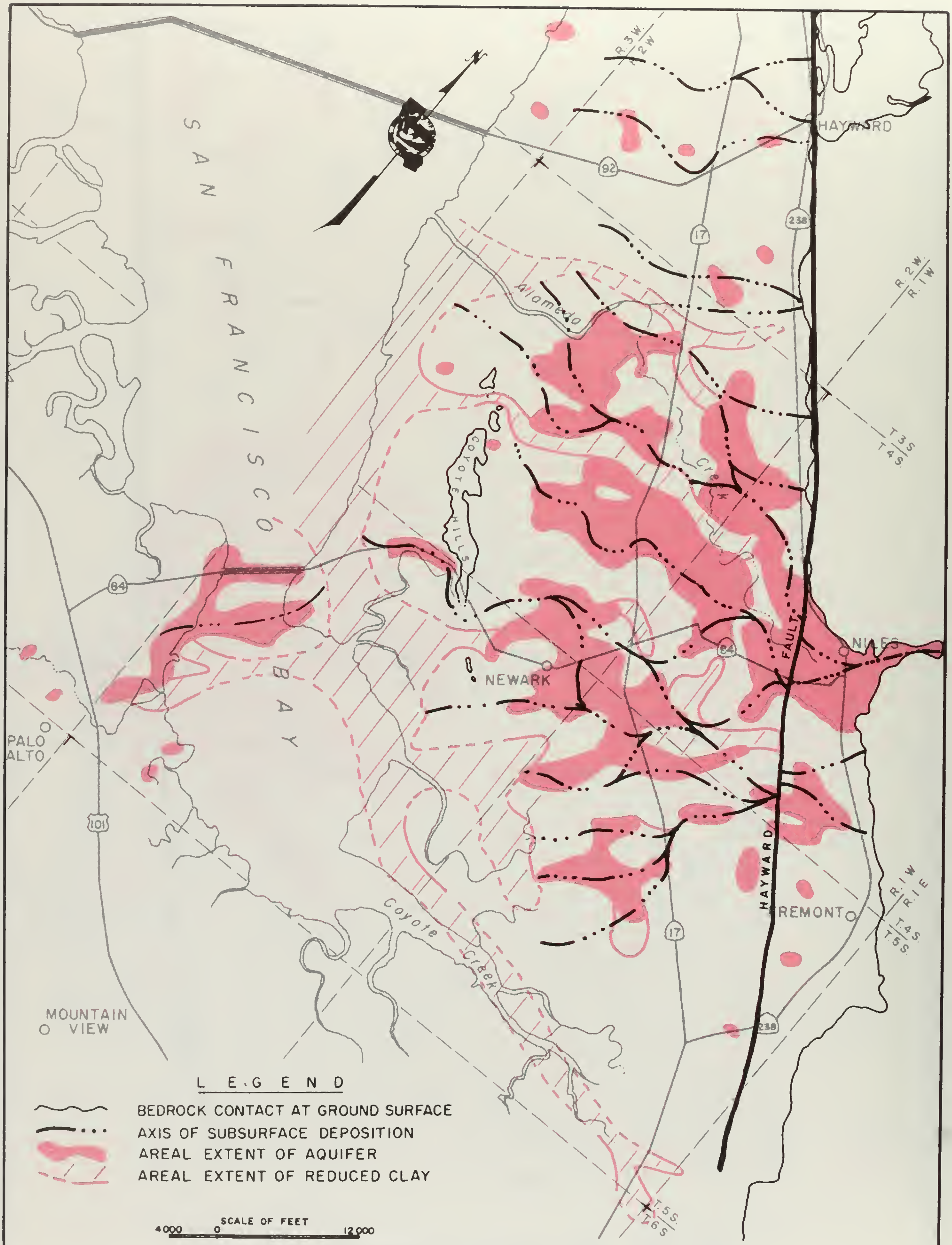



Figure 3. SUBSURFACE DEPOSITIONAL PATTERNS

SHEET 4 OF 8 ELEVATION INTERVAL -60 FEET TO -70 FEET


Figure 3. SUBSURFACE DEPOSITIONAL PATTERNS
SHEET 5 OF 8 ELEVATION INTERVAL -90 FEET TO -100 FEET

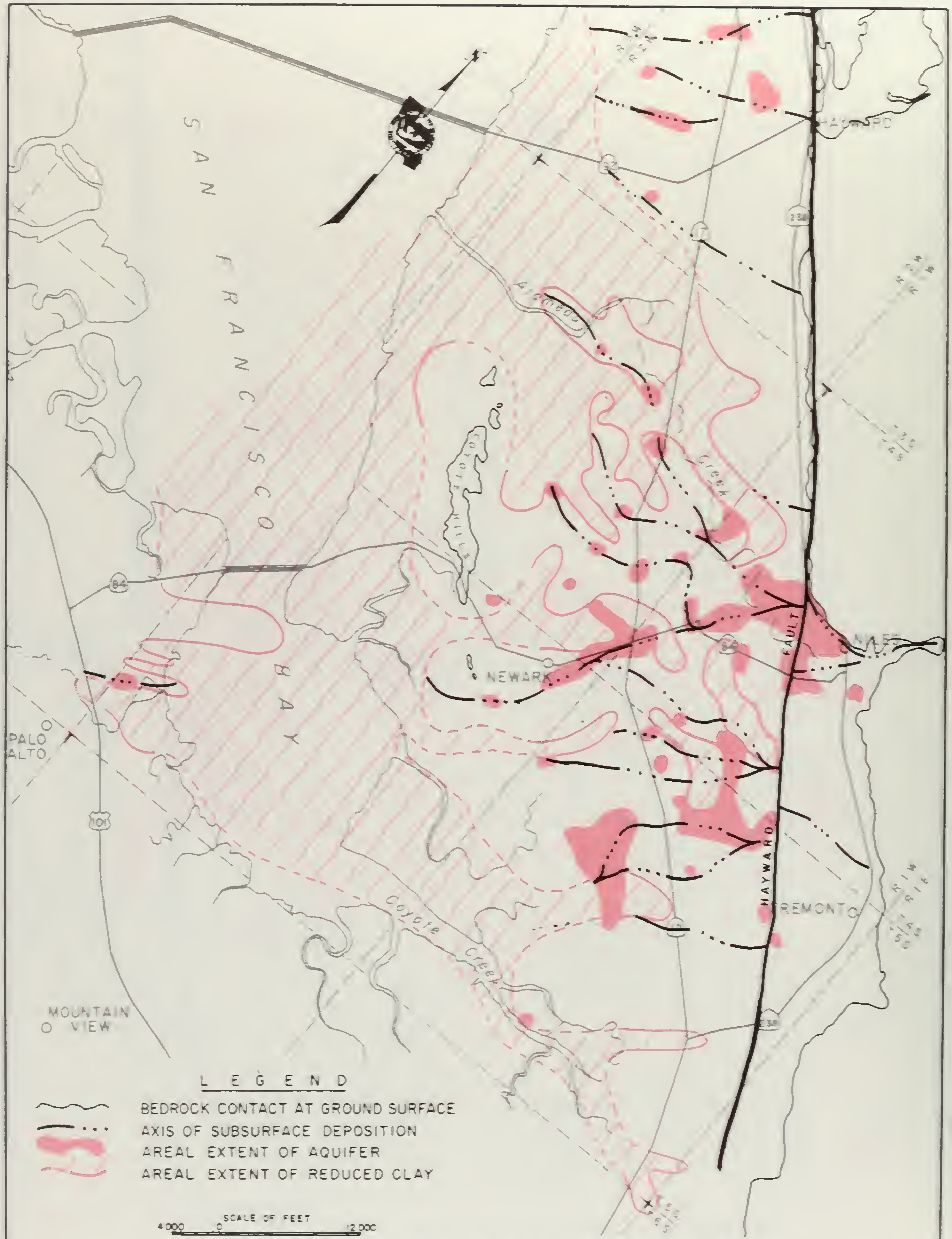



Figure 3. SUBSURFACE DEPOSITIONAL PATTERNS
SHEET 6 OF 8 ELEVATION INTERVAL -120 FEET TO -130 FEET

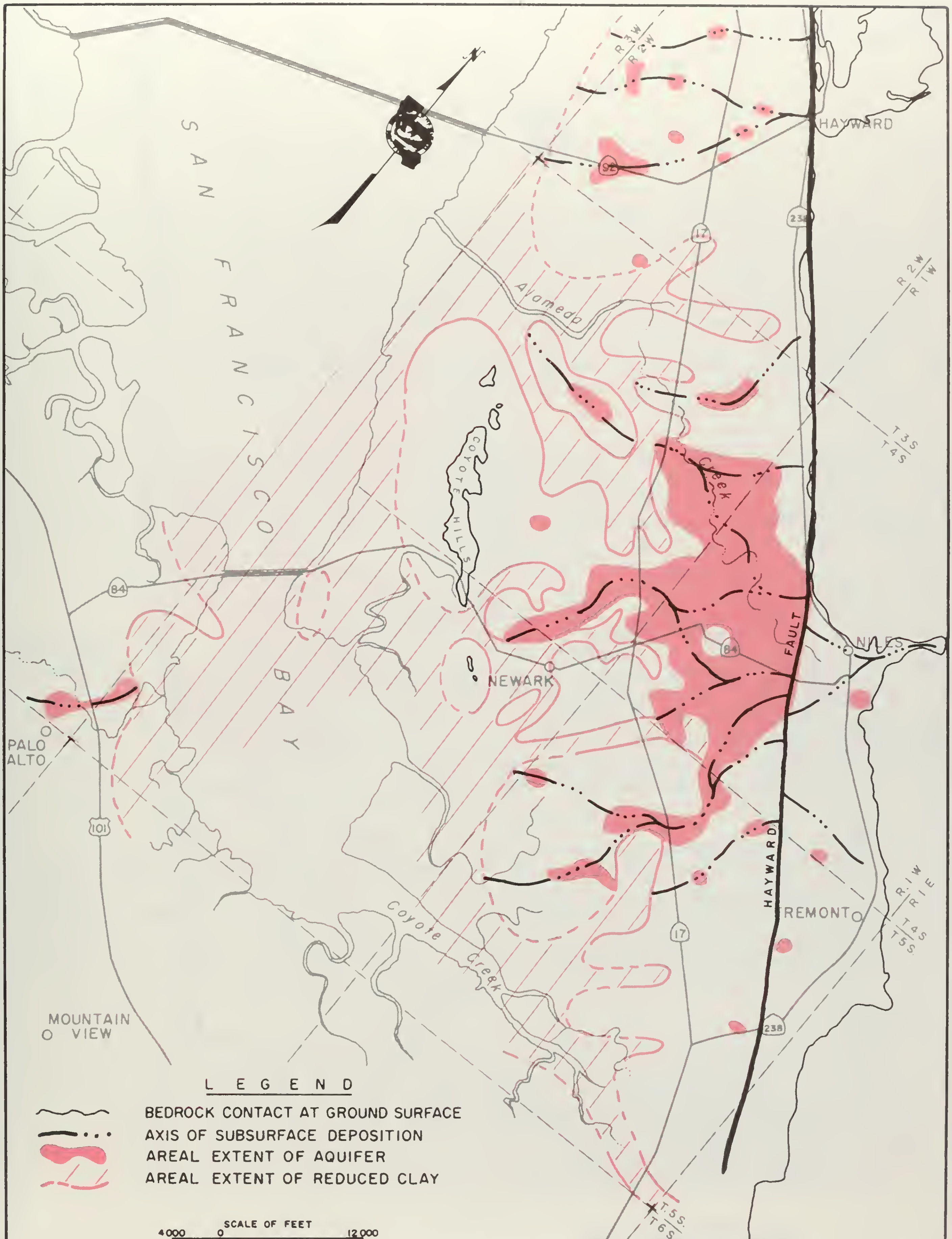



Figure 3. SUBSURFACE DEPOSITIONAL PATTERNS

SHEET 7 OF 8 ELEVATION INTERVAL -150 FEET TO -160 FEET

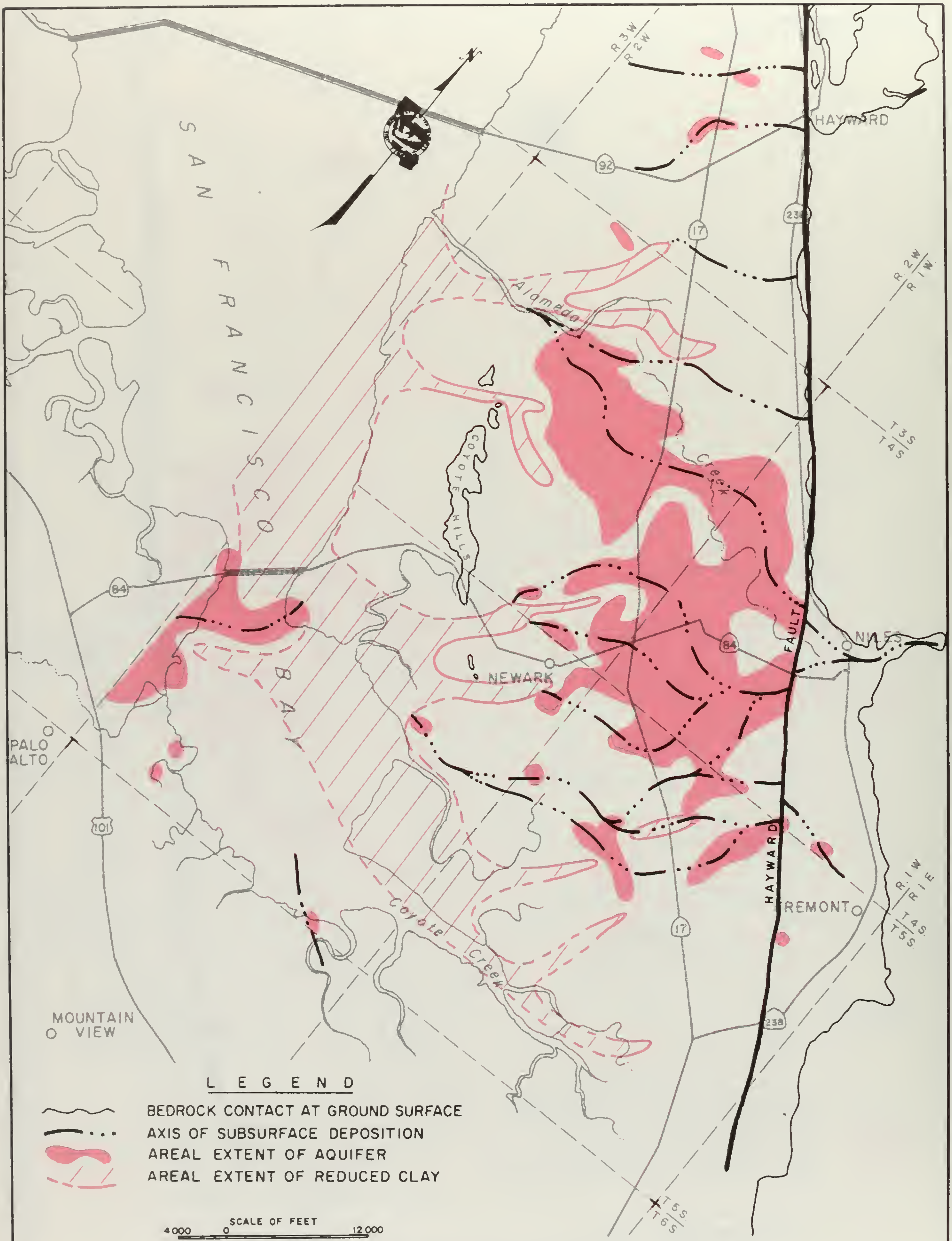



Figure 3. SUBSURFACE DEPOSITIONAL PATTERNS
SHEET 8 OF 8 ELEVATION INTERVAL -180 FEET TO -190 FEET

## CHAPTER III. AQUITARD CHARACTERISTICS

Nonsteady (fluctuating) flow of ground water to wells has traditionally been analyzed by considering each aquifer as an independent geologic and hydrologic unit. In the Fremont area at least three such aquifers exist, e.g., the Newark, Centerville, and Fremont Aquifers. Each of these aquifers is confined from above and below by layers that are of significantly less permeability. These layers, previously identified as aquicludes, have been found to possess definite permeability characteristics, to be compressible to some degree, and to release some water from storage. The descriptive term now applied to these confining beds is aquitards. Aquifers above or below the aquitards are termed leaky aquifers.

Because leakage suggests that there is some degree of hydraulic continuity between aquifers that are separated by an aquitard, the behavior of each aquifer is closely related to the behavior of the entire system. Hence, the group of aquifers and aquitards in the Fremont area should be considered as a multiple aquifer system rather than a group of individual aquifers.

### Oxnard Plain Studies and Their Relationship to Fremont Area

Recent studies in the Oxnard area of Southern California sponsored by the Department of Water Resources and reported on in Bulletin 63-4, "Aquitards in the Coastal Ground Water Basin of Oxnard Plain, Ventura County", September 1971, indicate that aquitards play a very important role in the overall ground water systems of coastal ground water basins. The layering of aquitards and aquifers at Oxnard are analogous to those in the Fremont area and the role of the aquitards in both areas have similarities.

The aquitards in the Oxnard basin were found to have an average vertical permeability of about $10^{-6}$ cm/sec (0.02 gpd/ft$^2$). Bulletin 81, "Intrusion of Salt Water into Ground Water Basins of Southern Alameda County", December 1960, reported a vertical permeability value range of 0.002 to 0.016 gpd/ft$^2$ per foot of head for the Irvington Aquitard. Sensitivity analysis using the mathematical model of the Fremont study area made in 1967 indicated vertical permeability of the Irvington Aquitard separating the Newark and Centerville Aquifers (Figure 2) is in the 0.002 to 0.012 gpd/ft$^2$ range.

After giving consideration to distance from the apex of the depositional cones, the effect of the Coyote Hills and the depositional environment, it is estimated that the permeability of the Newark aquitard east of the Coyote Hills is at least $10^{-5}$ cm/sec (0.2 gpd/ft$^2$), while under the Bay it is assumed to be $10^{-6}$ cm/sec (0.02 gpd/ft$^2$). The permeability of the deeper Irvington aquitard is believed to be $10^{-7}$ cm/sec (0.002 gpd/ft$^2$). There are two reasons for the differences in permeability: (1) the clays in the Newark aquitard are composed of mixtures of

reduced and oxidized clays, while those in the Irvington aquitard are primarily reduced clays; and (2) the Newark aquitard includes more small subsurface channels than the Irvington aquitard. With an assumed permeability of $10^{-6}$ cm/sec (0.02 gpd/$ft^2$) for the Newark aquitard and under a unit gradient of 1 ft/ft, about 560,000 gpd, or 630 acre-feet per year, may move vertically across an aquitard having an area of one square mile. In the Fremont area, where there is a landward gradient in the Newark aquifer, it is possible for salt water from San Francisco Bay to enter the overlying aquifer zone, which crops out on the floor of the Bay. With a gradient of only 0.1 ft/ft, and a permeability of $10^{-6}$ cm/sec (0.02 gpd/$ft^2$) the amount of water that would pass through the aquitard underlying the Bay would be on the order of 60 acre-feet per year per square mile. Assuming that about 100 square miles of aquitard are overlain by saline waters, about 6,000 acre-feet of Bay water could move into the aquitard each year provided there is a downward hydraulic gradient.

With this amount of Bay water moving into the aquitard, the velocity of movement becomes of great importance, as this will set the time span for the water to pass through the aquitard and into the underlying aquifer. Assuming a vertical gradient of unity, and a permeability of $10^{-6}$ cm/sec, the Darcy velocity of water moving through the aquitard is one foot per year. Hence, in an aquitard which has a thickness of about 50 feet, and assuming a porosity of 50 percent, it would take about 25 years for water to pass through. However, if the vertical gradient is on the order of 0.1 ft/ft, the time factor is increased 10 times (25 to 250 years). If the thickness is only 10 feet, then under the latter conditions, it would take 50 years for salt water to move through it.

In addition to the movement of fluids through an aquitard due to purely hydraulic gradients, there is another force which may move ions through relatively impermeable materials. This is the chemico-osmotic diffusion of chloride ion through an aquitard which has a high concentration of chloride on one side and a low concentration on the other. This may be the case under two conditions in the Fremont study area. First, it may occur in areas where saline water overlies zones of good quality water in the Newark aquifer but is separated from it by the Newark aquitard. Second, it may occur at inland areas of intruded Newark aquifer which are underlain by lower aquitards and aquifers containing fresh ground water. In cases such as these, there is a coupling between solute concentration gradient ground water flow, i.e. the mechanism by which a salt concentration gradient causes ground water flow and a hydraulic gradient causes salt flow. This phenomenon is termed chemico-osmotic coupling.

In the studies at Oxnard, it was found that an aquitard which had a permeability of $10^{-7}$ cm/sec (0.002 gpd/$ft^2$) and separating a saline solution having 36,000 ppm chloride from fresh ground water, underwent definite chemico-osmotic diffusion. Curves developed from the study showed that if the aquitard had a thickness of 30 feet and there was no difference in piezometric heads above and below it, then it would take about 800 years for the chloride ion to diffuse through the aquitard. However, impressing a head differential of 10 feet toward the zone of fresh water reduced this travel time to 250 years.

The studies also showed that the rate of diffusion varies according to the square of the thickness of the aquitard. Hence, if the thickness of the aquitard was reduced from 30 to 10 feet, the 250-year travel time would be reduced to 30 years.

Furthermore, if the thickness was reduced to only one foot, the travel time would be very small, only 0.3 year.

Finally, the time required for the concentration of chloride ion to increase to 1,500 ppm in an underlying aquifer was computed at Oxnard for various thicknesses of aquitard, all at a hydraulic gradient of 1/3 ft/ft. With the 30-foot thick aquitard, it was found that it would take 1,050 years for the underlying aquifer to attain a concentration of 1,500 ppm chloride by chemico-osmotic diffusion. However, with a thickness of 10 feet, this time is reduced to 70 years, and with a thickness of only one foot, the time is further reduced to only 4 years.

## Current Investigation

During 1971-72, a study of aquitard properties in the Fremont area was started under the guidance of Professor Paul A. Witherspoon of the University of California at Berkeley. Five shallow test holes were drilled using augers of different types and sizes, depending upon depth and type of material to be drilled. The locations of the test holes are shown on Figure 4.

During the drilling each change in lithology with depth was recorded, as well as a description of the material recovered. For each foot of hole drilled, a sample between three inches and one foot long was recovered from the auger. Care was taken to prevent contamination of the recovered cores from fresh water used in cleaning the auger or from surface soil and dust. The core sample immediately was placed into a labeled glass jar which was tightly capped. The samples obtained during a day's work were put in plastic bags and kept in the humidity room until the laboratory work could be done. The samples thus obtained are considered to be basically "undisturbed" and at field water content. During the laboratory procedures, care was taken to prevent evaporation.

Each of the core samples was divided into two parts. One was used to determine the water content of the soil; the other was used for the actual determination of the pore fluid salt concentration. Laboratory work was done at 20°C, and the results were adjusted to standard resistivities at 25°C.

The quantity of soluble salts (equivalent NaCl) in the pore fluid of the Newark aquitard materials, as estimated for several samples in each test hole, is presented in Figure 4 as graphs of depth in feet versus total dissolved solids in parts per million. The maximum values of salt concentration for each test hole are shown in Table 2.

There is a striking difference between the maximum salt concentrations of samples from test holes that are not in the area of salt ponds (but less than a mile away) and those that are directly in the area of salt ponds. The first two have a maximum salt concentration in the range of 2,500 ppm to 3,800 ppm (Test Holes A and B, Table 2), whereas the ones in the area of salt ponds (Test Holes C, D, and E) have salt concentrations that range from 17,500 to 60,000 ppm. The high values indicate that salt water has thoroughly invaded the aquitard layers. Fresh water is generally considered to contain less than 900 ppm


LOCATION MAP

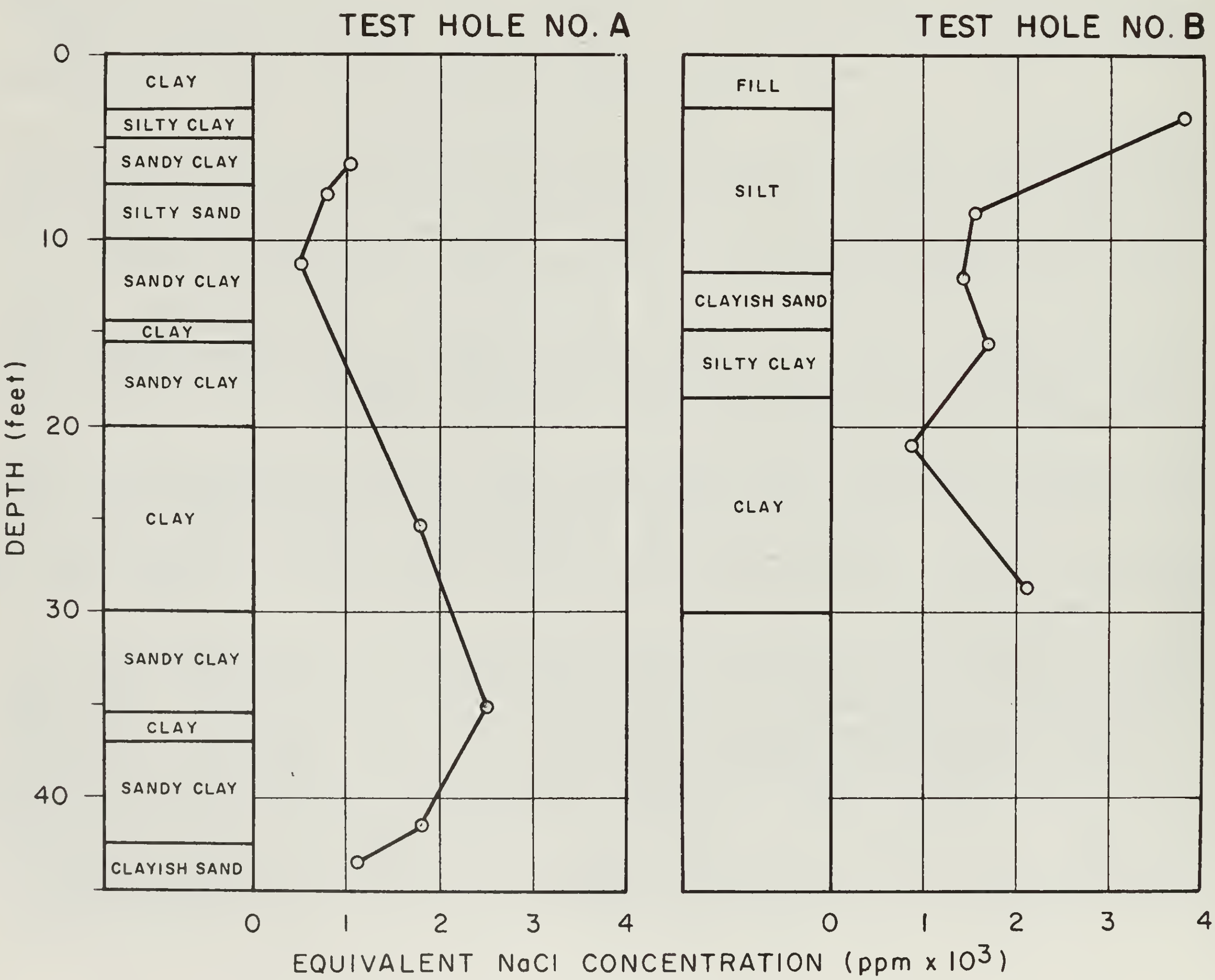



FIGURE 4: SALT CONCENTRATIONS IN NEWARK AQUITARD

SHEET 1 OF 2

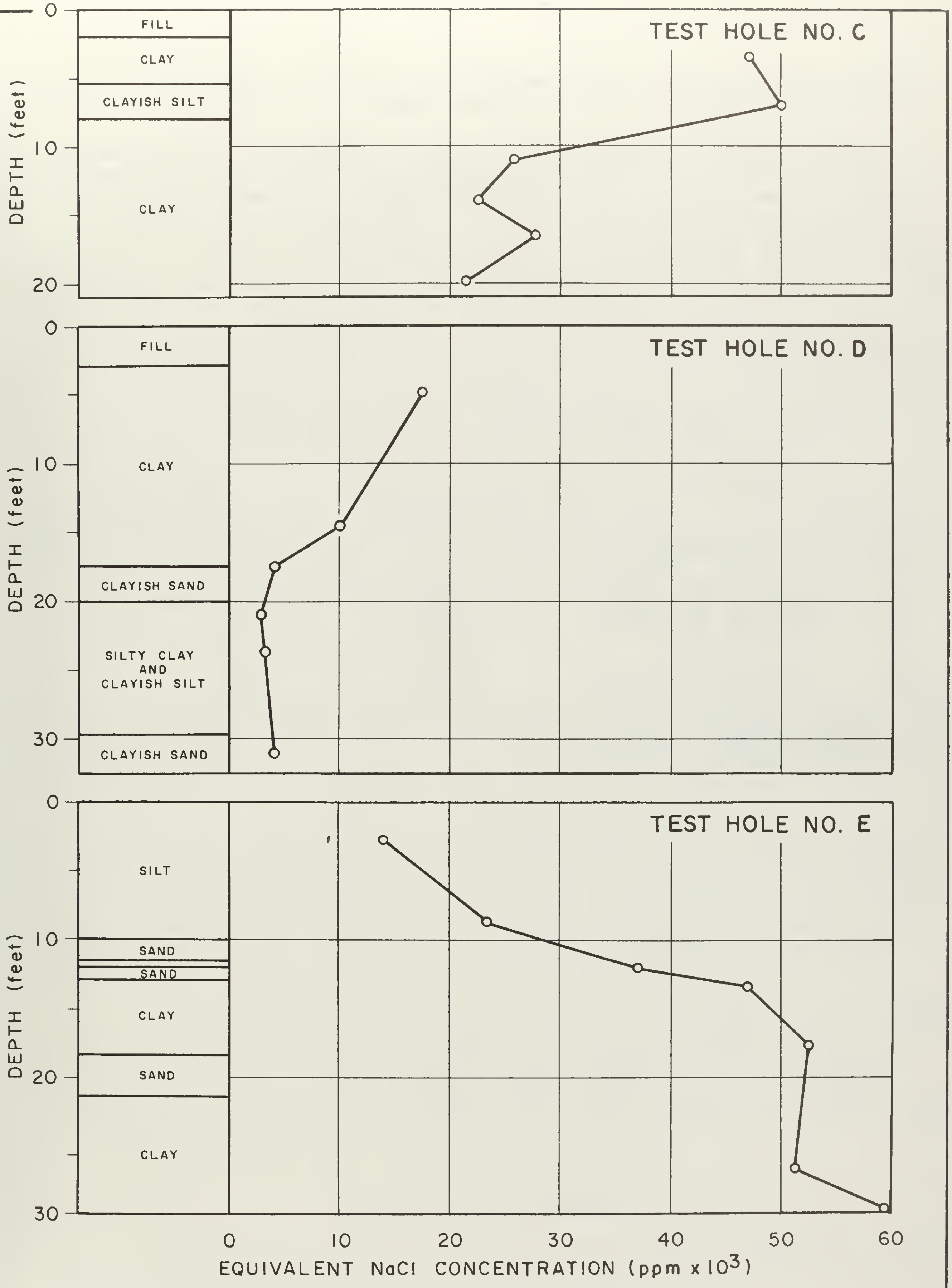



FIGURE 4: SALT CONCENTRATIONS IN NEWARK AQUITARD
SHEET 2 OF 2

chloride ion; ocean water approximately 19,000 ppm; South Bay waters range from 11,000 to 18,000 ppm; and salt evaporation ponds up to 215,000 ppm.

It appears that since some of the salt concentrations in the aquitard exceed the salt concentration in the South Bay waters, salt pond waters may constitute a source of degradation of the underlying aquifers. The mechanism for this salt water migration may be the result of a combination of two factors: chemico-osmotic diffusion, and a hydraulic gradient.

TABLE 2

SALT CONCENTRATIONS IN AQUITARD PORE WATER

| Test Hole No.* | Location | Maximum Salt** Concentration (ppm) | Formation | |
|---|---|---|---|---|
| | | | Type | Depth (feet) |
| A | Outside Salt Pond | 2,500 | Sandy Clay | 34 |
| B | Outside Salt Pond | 3,800 | Silt | 3 |
| C | In Salt Pond | 50,000 | Silt | 7 |
| D | In Salt Pond | 17,500 | Clay | 10 |
| E | Adjacent Salt Pond | 60,000 | Clay | 30 |

* Locations shown on Figure 4.
** Equivalent NaCl concentration.

# CHAPTER IV. SALINE WATER INTRUSION, STATUS AND CONTROL

Intrusion of saline water into the portion of the ground water area north of the Coyote Hills was evident by 1924. Degradation continued and ground water in the shallow, or upper, Newark aquifer became progressively more unsuitable for irrigation use. The ranchers, in their search for suitable irrigation supplies, drilled wells deeper into the second, or Centerville aquifer, which is separated from the Newark aquifer by a nearly impermeable clay layer. Fresh water from deeper aquifers relieved the immediate problems, and the extent of the intrusion of saline water was not fully realized until 1950, when degraded water first began to appear in the Centerville aquifer. The salinity was first noticed in the Alvarado-Newark-Centerville area, and spread over a larger area.

Degradation of ground water by intrusion of saline water is probably caused by a combination of a number of conditions. The Newark aquifer is not in direct contact with San Francisco Bay except for localized areas where tidal currents or dredging may have scoured the bay mud and exposed the aquifer. Saline water may be entering the aquifer through openings in the bay mud and the clay cap, both of which overlie the aquifer, or the clay cap may have been breached by abandoned, unsealed wells.

Intrusion is caused by saline water from the bay and salt ponds flowing through breaks in the clay cap and the clay cap itself and into the Newark aquifer, under the pressure differential existing between the bay surface and the aquifer. Although the downward flow of salt water per square foot of area is very small, the annual amounts over the total area of bay and salt ponds can be large.

The hydraulic conditions allowing saline water intrusion and the paths of intrusion are shown on Figure 5. Pumping from the Centerville and deeper aquifers created a hydraulic depression, or trough, in the water levels east of the Bay. Thus the hydraulic gradient in these aquifers is bayward from the forebay and landward from the bay. The forebay is connected to all of the aquifers and receives recharge from the surface. The hydraulic gradient in the Newark aquifer during periods of intrusion is landward from the bay to the forebay.

Under these hydraulic conditions, saline water enters the portion of the Newark aquifer under the bay and the salt ponds. It then moves landward toward the forebay, and enters the lower aquifers by way of the forebay or by passing through the thin clay layers near the forebay. After the saline water has entered a lower aquifer, it then moves bayward down the hydraulic gradient toward the pumping depression.

## Extent of Saline Intrusion

Figure 6 depicts lines of equal elevation of ground water and the status of salt water intrusion by isochlors (lines of equal chloride concentration in the ground water) in the Newark and Centerville-Fremont aquifers in the spring of 1970. The

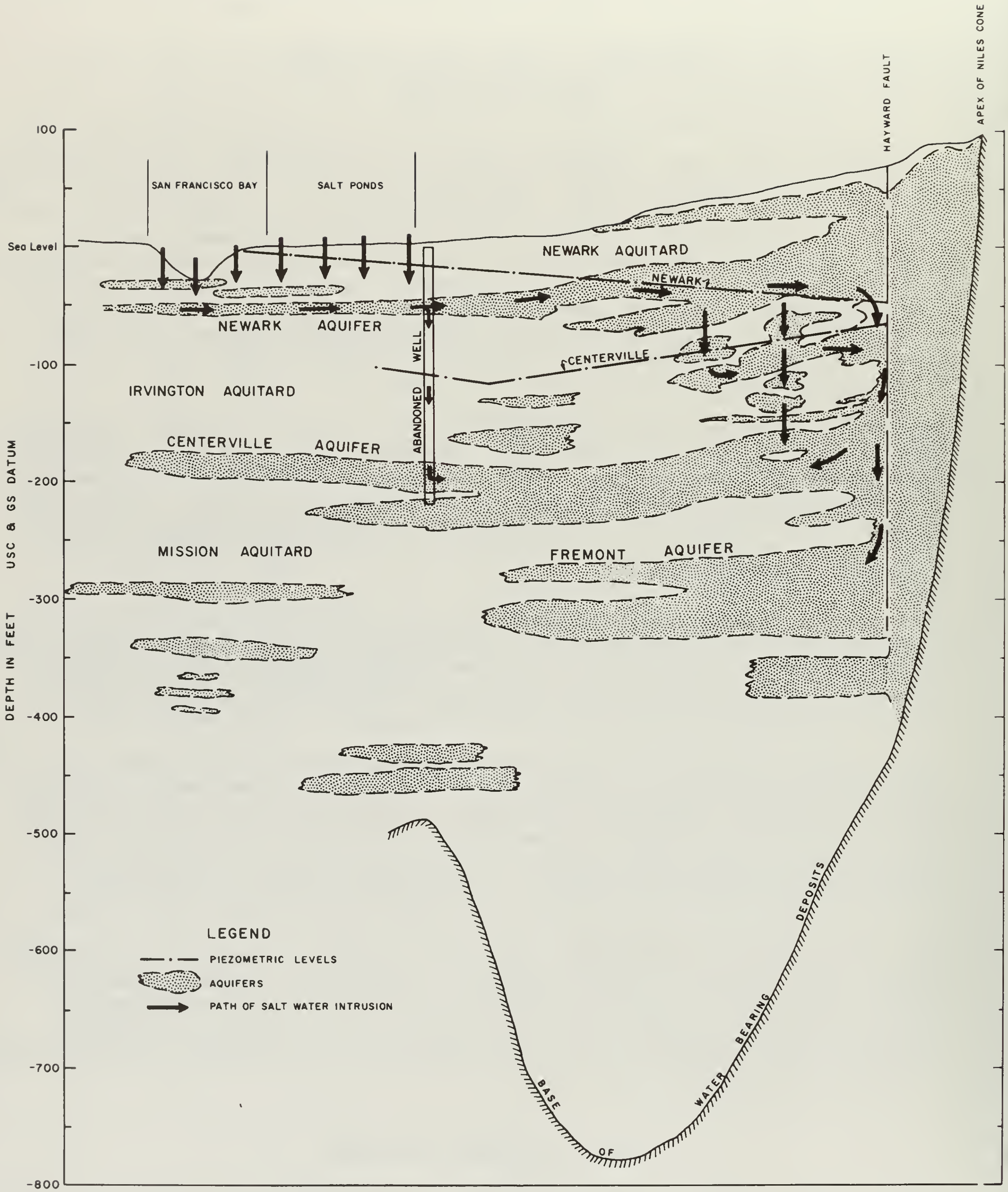
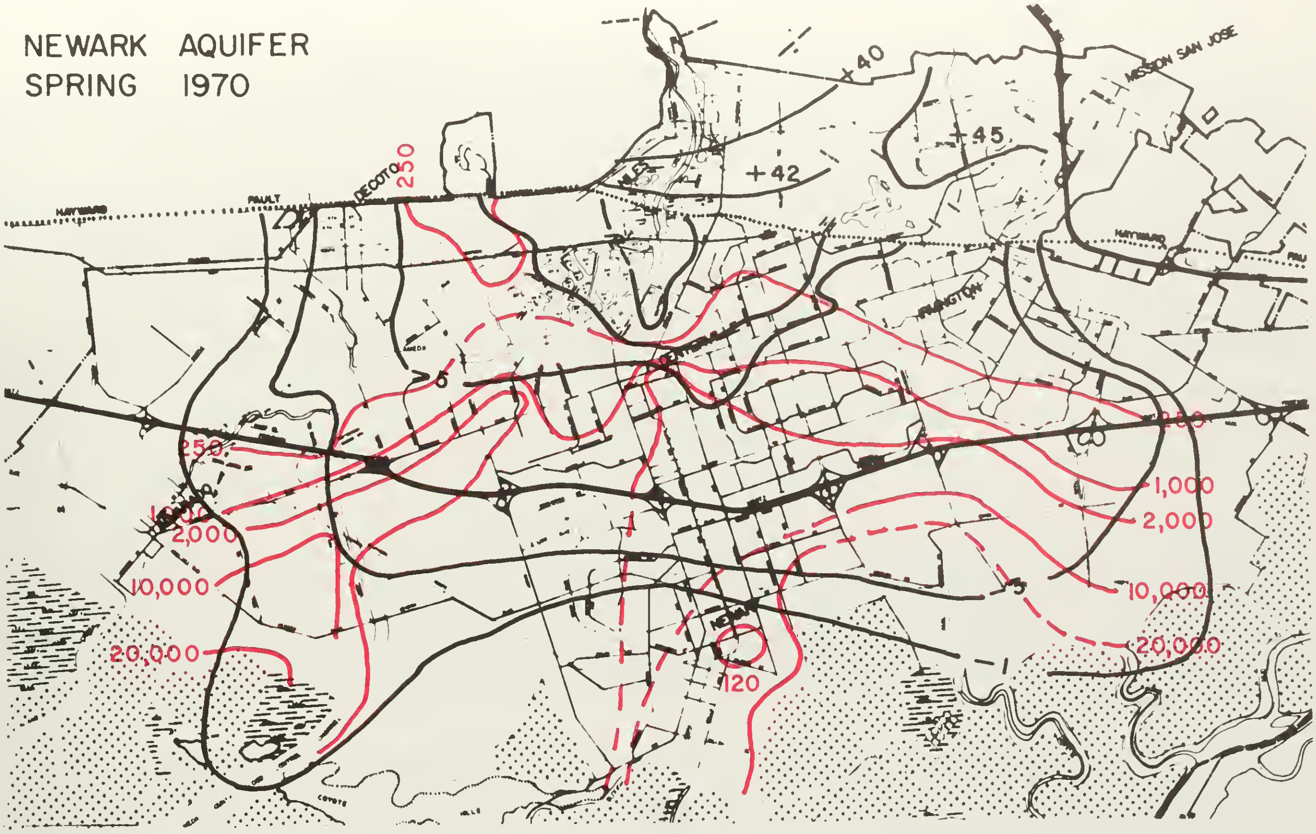



Figure 5. INTRUSION OF SALT WATER INTO THE FREMONT STUDY AREA (SCHEMATIC)

NEWARK AQUIFER
SPRING 1970




LEGEND

LINES OF EQUAL ELEVATION OF GROUND WATER IN FEET + 40

LINES OF EQUAL CHLORIDE CONCENTRATION IN PPM 250 PPM

CENTERVILLE
FREMONT-AQUIFER
SPRING 1970

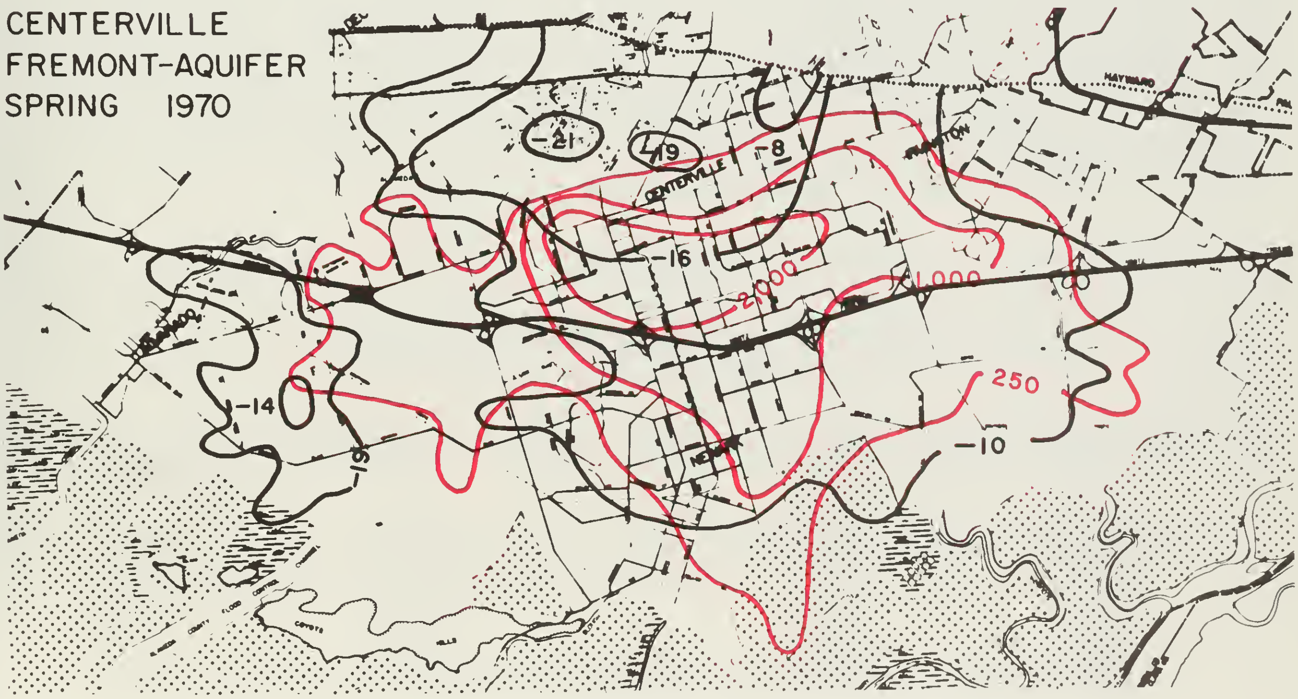



FIGURE 6 : GROUND WATER CONTOURS AND ISOCHLORS

figures should be considered as a graphic display of chloride concentration distribution rather than an exact comparison because the number of control points used and their locations are not constant.

The area of the Newark aquifer with salt concentrations in excess of 250 ppm chloride decreased about 600 acres from approximately 21,100 acres in 1963 to about 20,500 acres in 1972. The area of the Centerville-Fremont aquifer with salt concentrations greater than 250 ppm chloride increased about 3,000 acres from approximately 8,800 acres in 1963 to approximately 11,800 acres in 1972.

## Volume of Saline Intrusion

To determine the total volume of intrusion which has taken place, it is necessary to assign an average salinity to the intruding waters. The two sources of intrusion are: the Bay, with salinities varying between 10,600 and 18,900 ppm; and the salt evaporation ponds, with salinities varying from that of the Bay to 215,000 ppm. A composite salinity averaging 21,000 ppm was chosen to represent intruding water, since this appears to be the average salinity of ground water in the upper aquifer around the perimeter of the Bay.

The volume of salt water present in each of the aquifers in the spring of the years 1963 and 1972 are based on the isochlors, the salinity of intruding water (21,000 ppm), and the storage capacities of the aquifers. The annual amounts of saline water intruding the ground water basin were estimated by prorating the total amount of saline water between 1963 and 1972 on the basis of water levels in the forebay area bayward from the Hayward Fault. The annual amounts are listed in Table 3.

Although the total amount of salt in the basin has increased between 1963 and 1972, the annual rate of salt water entering the basin decreased from 1963 to 1972 due to the Alameda County Water District's ground water recharge program. The reduction in annual salt water intrusion rates would have been greater except for pumpage and wastage of water from the basin by the gravel quarries for more economic gravel extractions, and the interruptions in the recharge operations caused by the construction of the Alameda Creek Flood Control Channel. The wastage of pumpage to the Bay has been stopped and the construction of the flood control channel has been completed.

TABLE 3

ANNUAL AMOUNTS OF SALINE* INTRUSION
(In Acre-Feet)

| Year | Amount | Year | Amount |
|---|---|---|---|
| 1961-62 | 8,600 | 1966-67 | 3,100 |
| 1962-63 | 6,600 | 1967-68 | 1,100 |
| 1963-64 | 6,800 | 1968-69 | 1,100 |
| 1964-65 | 5,400 | 1969-70 | 1,700 |
| 1965-66 | 5,000 | 1970-71 | 1,700 |

*Saline water at 21,000 ppm equivalent salinity.

## Effect of Saline Intrusion on Water Supply

During the study period the total amount of water supply available to the area has exceeded the total water use. The net result of this relationship and saline intrusion is shown by the well hydrographs in Figure 7. Annual amount of water use is the sum of ground water pumped and direct delivery of imported water to customers, and is shown in Table 4.

The hydrologic inventory in Chapter V shows that during the period 1961 to 1969, the total amount of water in storage increased by 76,000 acre-feet. Of this increase, 38,000 is attributable to saline intrusion and 38,000 to fresh water. During the two-year period 1969-71 there has been a decrease of water in storage of 11,000 acre-feet. This was the result of extractions exceeding fresh water recharge by 14,000 acre feet and a saline intrusion of 3,000 acre-feet.

Although the water levels have recovered and water supply available has exceeded water use, a part of the water level recovery was due to saline intrusion and results in a continuing presence of salt water within the basin. The ground water basin is still endangered, not only from the large amount of salt water now present in the basin, but also from the probability of additional intrusion during future dry periods.

TABLE 4

ANNUAL AMOUNTS OF WATER USE
(In Acre-Feet)

| Year | Amount | Year | Amount |
|---|---|---|---|
| 1961-62 | 43,800 | 1966-67 | 44,400 |
| 1962-63 | 39,300 | 1967-68 | 48,500 |
| 1963-64 | 45,400 | 1968-69 | 54,400 |
| 1964-65 | 46,600 | 1969-70 | 53,700 |
| 1965-66 | 49,200 | 1970-71 | 48,900 |

## Control of Saline Intrusion

Various methods of protecting the ground water basin against further intrusion and for removal of the existing salts have been reviewed. A pumping barrier is recommended as the basic plan deserving further study and the plan which can be used to judge other alternatives. This type of plan is recommended because it will not cause saline water inland of the proposed barrier location to be forced farther inland into fresh water areas such as a recharge mound type of barrier would do, and the pumping barrier will assist in the removal of salt water from the upper aquifer.

Previous work by the Department in both the Oxnard and Fremont areas assures that a pumping barrier is physically feasible.

The magnitude of the cost of installing a pumping barrier was arrived at by developing the conceptual plan shown on Figure 8. The barrier plan is anchored on the Coyote Hills and uses 14 pumping wells to form a protective arc around the major production portions of the Newark aquifer. The capital cost of the system including wells, pumps, monitoring points and equipment, lands, discharge facilities and power service is estimated to be $1.2 million. The annual operations, maintenance and replacement costs are estimated to be $100,000.

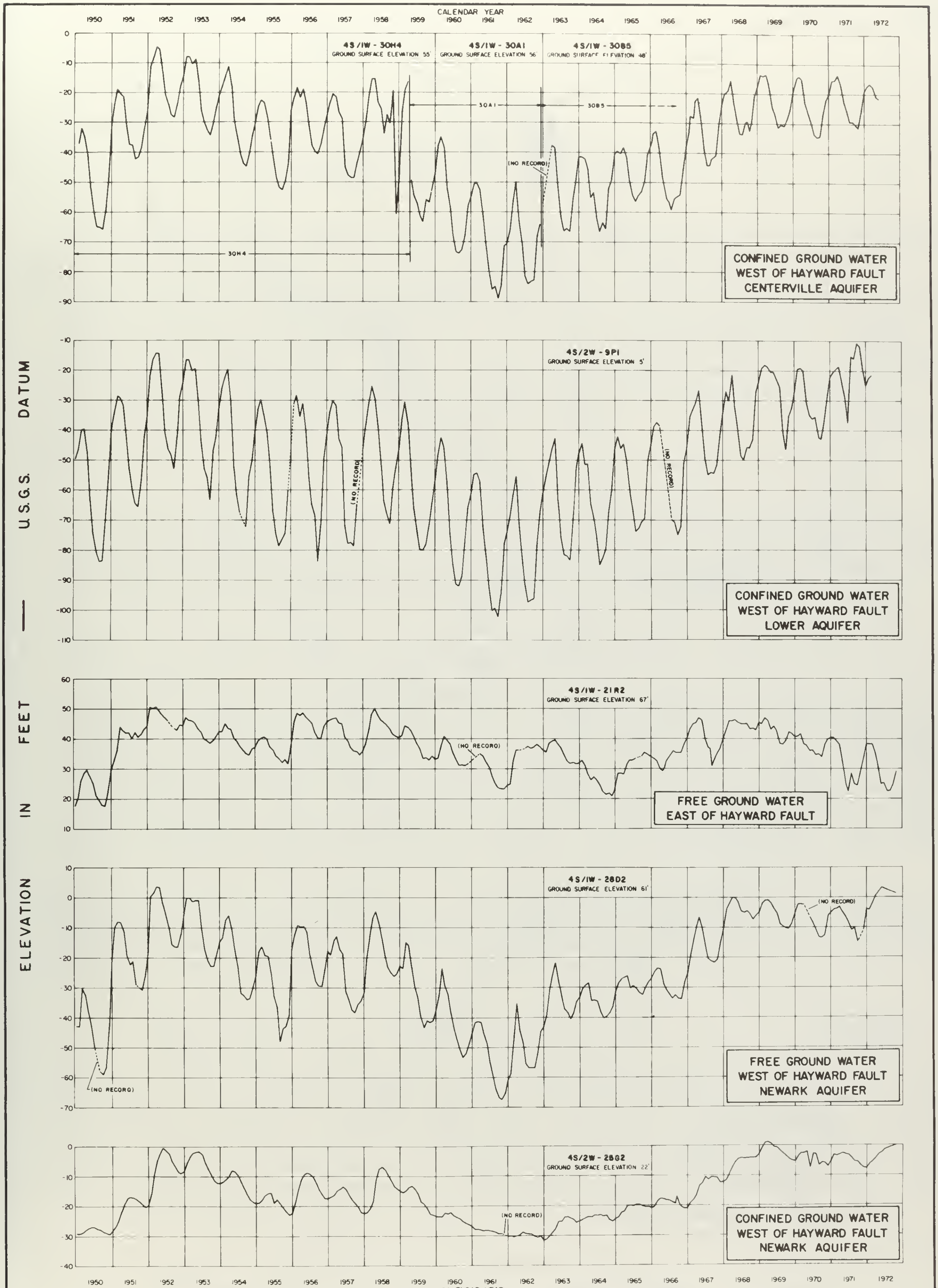



Figure 7. HYDROGRAPHS AT SELECTED WELLS

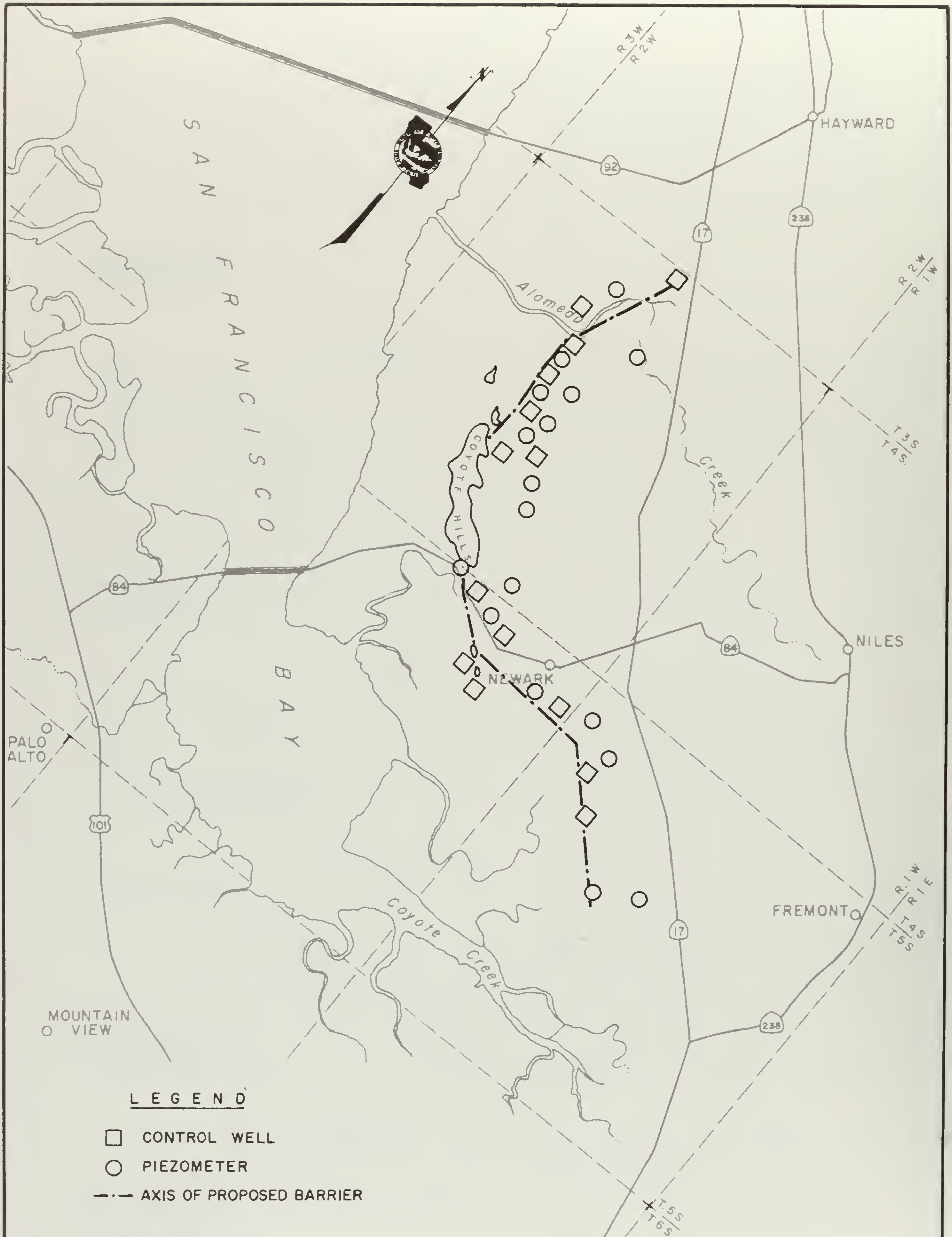



Figure 8. CONCEPTUAL PLAN FOR PROPOSED BARRIER

# CHAPTER V. EVALUATION OF HISTORIC WATER SUPPLY AND DISPOSAL

The development of an inventory of supply to and disposal from the ground water basin provides a gross view of how the ground water basin is affected by climate and man's works. When the inventory is performed on many small pieces of the basin, as in modeling, the operational characteristics of the basin become clear. In both the gross inventory of the basin and in the modeling approach, supply and disposal are combined to obtain a theoretical change in storage. These changes are compared to the historic changes to verify the accuracy of the inventory and model. The model may then be used to test alternative plans for protection and operation of the ground water basin.

## Study Area

The Fremont study area is the subsurface area influenced by Alameda Creek and adjacent smaller streams, and represents a manageable unit of the South Bay Ground Water Basin. For the purposes of this report the study area shown on Figure 1 has been approximated by the ground water model shown in Figure 9.

## Ground Water Model

The model configuration shown in Figure 9 is a modification of that described in Appendix E of the 1968 report. The area covered by the model has been enlarged to better approximate the study area. The arrangement of individual nodal areas (polygons) has been modified to conform to the more detailed geologic and hydrologic interpretations. The southern end of the study area is an area of overlap of depositions of Alameda Creek and Santa Clara streams. This overlap condition has been simulated by using nodes 22 through 26 of the Fremont model in the model of the Santa Clara ground water area.

For the purposes of this report, the amounts of recharge, pumpage and change in storage are shown for the total ground water basin. This information will be determined for each nodal area in the model, then verified and used for planning of the salinity barrier.

## Study Period

In selection of a segment of time to use as a study period, it is desirable to specify certain criteria. The hydrologic condition during the study period should reasonably represent a long-time hydrologic condition. The time segment selected should begin at the end of a dry period and should end at the conclusion of a dry period in order to minimize the difference between the amount of water in transit in the zone of aeration between the beginning and end of the study period. The time segment should be within the period of available records, and if recent

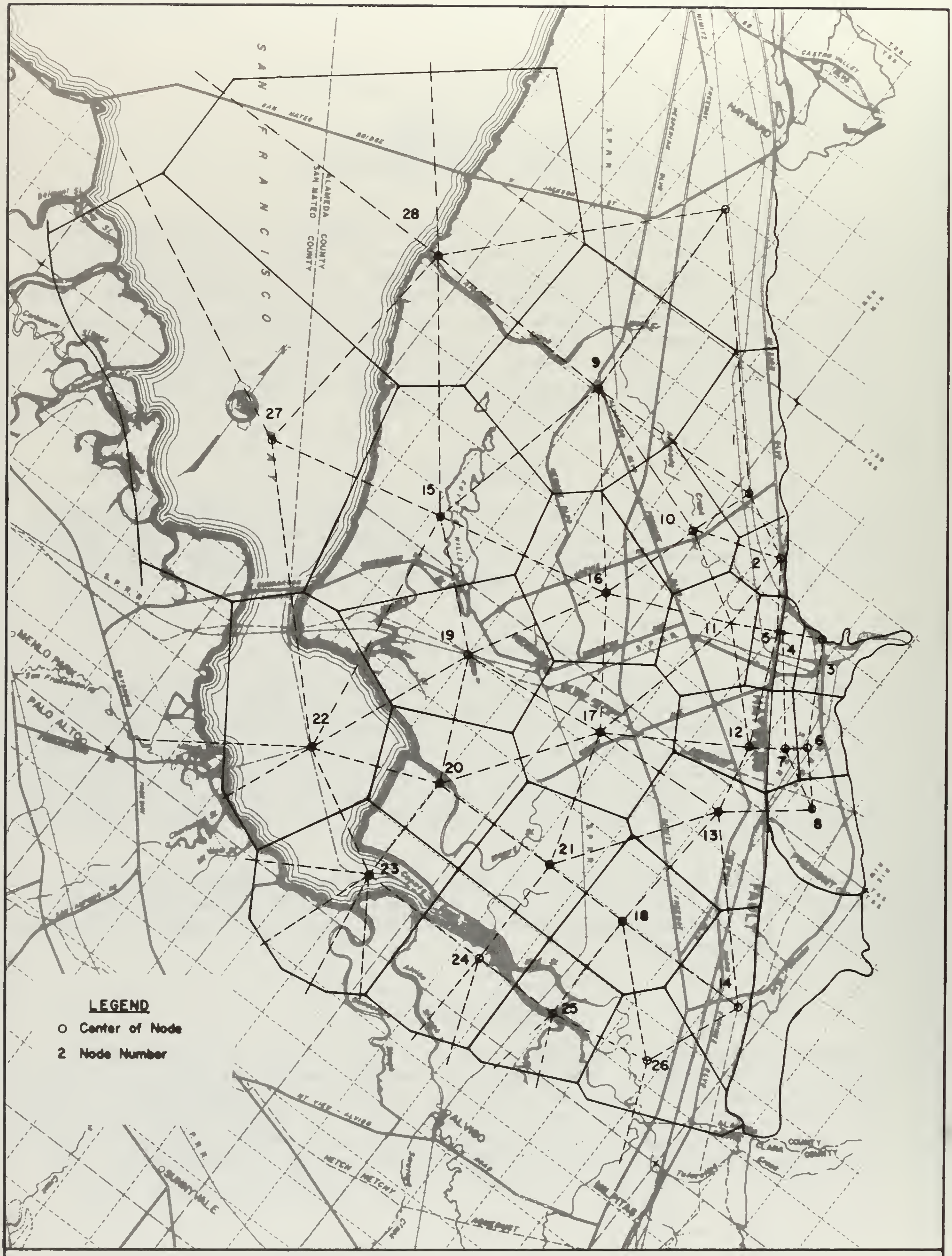



Figure 9. MATHEMATICAL MODEL

cultural conditions have been recorded, this information can aid in determination of the effect of urbanization on recharge to the ground water.

The August 1967 report used a 16-year study period, water years 1949-50 through 1964-65. This report uses a 9-year period, water years 1961-62 through 1969-70. The year 1961-62 was selected as the initial year because that year was the beginning of recharge of water from the State's South Bay Aqueduct and it was preceded by a year of below normal precipitation. The relative amounts of annual precipitation during the long term record, the base period, and the study period are shown on Figure 10. The long time average period of 94 years was not changed because the longer period of record now available did not change the average precipitation.

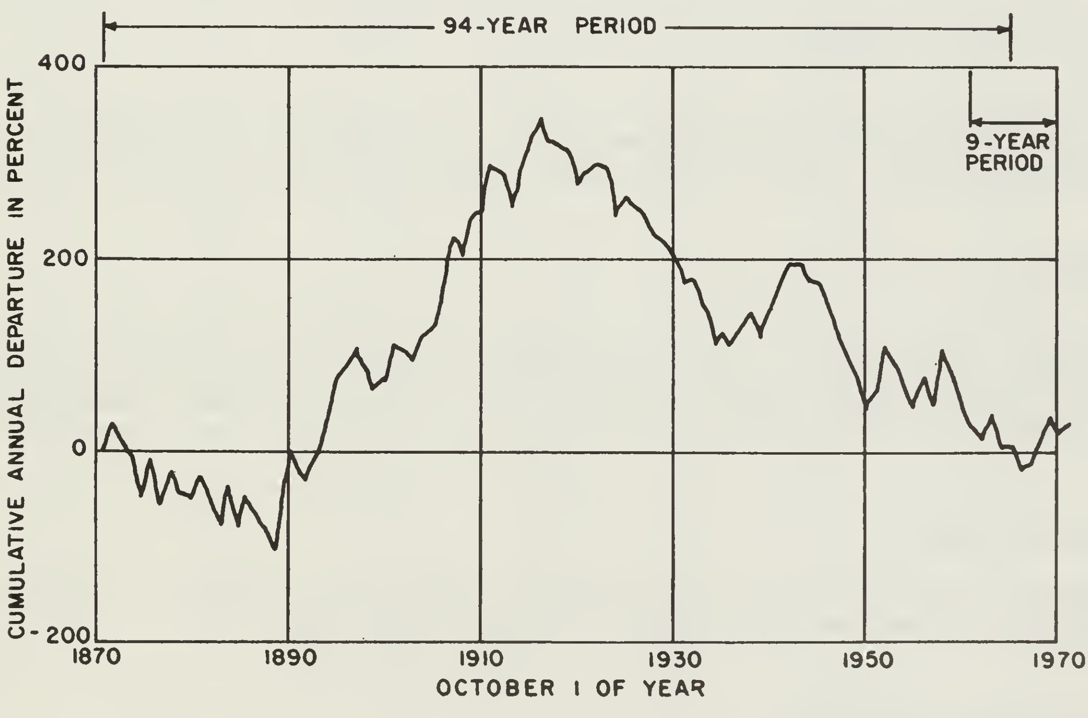



FIGURE 10 - CUMULATIVE DEPARTURE OF ANNUAL PRECIPITATION FROM 94 YEAR MEAN

## General Conditions

The general factors affecting the ground water basin are precipitation, streamflow, land use and imported water.

### Precipitation

Precipitation for the entire period of record for gages in the vicinity of Niles is shown in Table 5. The 94-year average used in the 1968 report has been retained as long term average, since the additional record had no effect on the average. The 9-year period 1961-62 through 1969-70 has about the same average annual precipitation as the 94-year average.

### Streamflow

Alameda Creek is the main stream traversing the forebay of the area. Flow measurements since 1891-92 are available for the creek where it enters the area near Niles and for three years, 1916-1919, for the lower end of the recharge area near Decoto. Main flows now leave the area by a new channel, Patterson Creek, but the old Alameda Creek continued to receive excess flows until 1967. Both of the outflow channels have been gaged since 1958-59. The Alameda Creek Flood Control Channel, which improved Patterson Creek, was completed beyond this point in 1967; thereafter all of the flows passed down that channel. Dry Creek, located near the upper end of the area and tributary to the Alameda Creek lower gage, is also measured.

Flows of other streams tributary to the study area were estimated by correlation with gaged streams. Recorded amounts of runoff are shown in Table 6. Estimated amounts of annual runoff from ungaged tributary areas are shown in Table 7.

### Land Use

The study area continues to be in transition from an agricultural to urban economy. The change in land use within the model area of 108,040 acres during the study period is shown in Table 8. Land use within the boundaries of the Alameda County Water District is shown on the plate following page 57.

### Imported Water

Agencies in the study area purchase water from two suppliers of imported water: the City of San Francisco and the State of California.

#### Annual Deliveries

Amounts of water imported from the City of San Francisco's aqueducts and from the State of California's South Bay Aqueduct are listed in Table 9.

TABLE 5

ANNUAL PRECIPITATION AND INDEX OF WETNESS
1871-1970

| Water Year | Inches a/ | Index of Wetness b/ | Water Year | Inches | Index of Wetness | Water Year | Inches | Index of Wetness |
|---|---|---|---|---|---|---|---|---|
| 1871-72 | 22.65 | 125 | 1905-06 | 24.20 | 133 | 1940-41 | 25.35 | 140 |
| 72-73 | 14.31 | 79 | 06-07 | 28.85 | 159 | 41-42 | 21.23 | 117 |
| 73-74 | 14.17 | 78 | 07-08 | 15.12 | 83 | 42-43 | 18.29 | 101 |
| 74-75 | 11.74 | 65 | 08-09 | 25.10 | 138 | 43-44 | 15.38 | 85 |
| | | | 09-10 | 18.65 | 103 | 44-45 | 16.82 | 93 |
| 1875-76 | 25.88 | 142 | 1910-11 | 27.59 | 152 | 1945-46 | 14.39 | 79 |
| 76-77 | 9.34 | 51 | 11-12 | 15.80 | 87 | 46-47 | 12.60 | 69 |
| 77-78 | 24.67 | 136 | 12-13 | 12.06 | 66 | 47-48 | 14.72 | 81 |
| 78-79 | 14.54 | 80 | 13-14 | 22.95 | 127 | 48-49 | 12.72 | 70 |
| 79-80 | 17.70 | 97 | 14-15 | 27.34 | 150 | 49-50 | 14.00 | 77 |
| 1880-81 | 20.14 | 111 | 1915-16 | 21.38 | 118 | 1950-51 | 20.21 | 111 |
| 81-82 | 13.91 | 77 | 16-17 | 13.50 | 74 | 51-52 | 26.26 | 145 |
| 82-83 | 14.07 | 78 | 17-18 | 18.15 | 100 | 52-53 | 15.50 | 85 |
| 83-84 | 25.88 | 142 | 18-19 | 17.49 | 96 | 53-54 | 13.50 | 74 |
| 84-85 | 10.36 | 57 | 19-20 | 11.06 | 61 | 54-55 | 14.90 | 82 |
| 1885-86 | 23.35 | 128 | 1920-21 | 20.62 | 113 | 1955-56 | 23.85 | 131 |
| 86-87 | 15.37 | 85 | 21-22 | 19.85 | 109 | 56-57 | 12.99 | 71 |
| 87-88 | 14.67 | 81 | 22-23 | 17.89 | 98 | 57-58 | 28.30 | 156 |
| 88-89 | 15.67 | 86 | 23-24 | 8.63 | 47 | 58-59 | 12.30 | 68 |
| 89-90 | 36.36 | 200 | 24-25 | 21.65 | 119 | 59-60 | 13.83 | 76 |
| 1890-91 | 14.04 | 77 | 1925-26 | 16.35 | 90 | 1960-61 | 14.03 | 77 |
| 91-92 | 16.18 | 89 | 26-27 | 18.79 | 103 | 61-62 | 15.86 | 87 |
| 92-93 | 23.72 | 131 | 27-28 | 16.55 | 91 | 62-63 | 22.58 | 124 |
| 93-94 | 23.19 | 128 | 28-29 | 14.48 | 80 | 63-64 | 11.99 | 66 |
| 94-95 | 26.63 | 147 | 29-30 | 14.78 | 81 | 64-65 | 18.14 | 100 |
| 1895-96 | 20.33 | 112 | 1930-31 | 12.22 | 67 | 1965-66 | 14.02 | 77 |
| 96-97 | 22.72 | 125 | 31-32 | 18.87 | 104 | 66-67 | 25.41 | 140 |
| 97-98 | 13.58 | 75 | 32-33 | 13.70 | 75 | 67-68 | 15.06 | 83 |
| 98-99 | 14.52 | 80 | 33-34 | 10.66 | 59 | 68-69 | 23.67 | 130 |
| 99-00 | 19.30 | 106 | 34-35 | 19.77 | 109 | 69-70 | 15.30 | 84 |
| 1900-01 | 25.22 | 139 | 1935-36 | 16.69 | 92 | 1970-71 | 19.96 | 110 |
| 01-02 | 17.12 | 94 | 36-37 | 19.78 | 109 | | | |
| 02-03 | 17.20 | 95 | 37-38 | 21.80 | 120 | | | |
| 03-04 | 21.91 | 121 | 38-39 | 13.33 | 73 | | | |
| 04-05 | 20.19 | 111 | 39-40 | 22.20 | 122 | | | |
| Averages | | | 94 years 1871-1965 | 18.17 | 100 | 9 years 1961-70 | 18.00 | 99 |

a/ 1871-72 thru 1884-85 Weather Bureau's Niles Precipitation Station (SP Depot)
1885-86 thru 1932-33 Niles 1 SW Precipitation Station
1933-34 thru 1957-58 Niles 1 S Precipitation Station
1958-59 thru 1969-70 Alameda County Corp. Yard Precipitation Station

b/ Index of Wetness is the percent of 94-year average.

TABLE 6

RECORDED ANNUAL RUNOFF
(In Acre-Feet)

Alameda Creek Near Niles

| Year | Amount | Year | Amount | Year | Amount |
|---|---|---|---|---|---|
| | | 1920-21 | 72,400 | 1950-51 | 115,200 |
| 1891-92 | 56,000 | 21-22 | 131,000 | 51-52 | 291,100 |
| 92-93 | 360,000 | 22-23 | 58,000 | 52-53 | 24,700 |
| 93-94 | 147,000 | 23-24 | 2,060 | 53-54 | 4,250 |
| 94-95 | 263,000 | 24-25 | 18,700 | 54-55 | 5,900 |
| 1895-96 | 118,000 | 1925-26 | 31,000 | 1955-56 | 214,100 |
| 96-97 | 204,000 | 26-27 | 48,300 | 56-57 | 7,880 |
| 97-98 | 7,020 | 27-28 | 30,100 | 57-58 | 245,700 |
| 98-99 | 64,100 | 28-29 | 5,240 | 58-59 | 14,660 |
| 99-00 | 51,700 | 29-30 | 19,200 | 59-60 | 11,940 |
| 1900-01 | 119,000 | 1930-31 | 1,220 | 1960-61 | 650 |
| 01-02 | 83,800 | 31-32 | 57,400 | 61-62 | 34,740 |
| 02-03 | 110,000 | 32-33 | 6,980 | 62-63 | 66,660 |
| 03-04 | 98,300 | 33-34 | 7,920 | 63-64 | 22,940 |
| 04-05 | 45,400 | 34-35 | 30,490 | 64-65 | 85,620 |
| 1905-06 | 203,000 | 1935-36 | 77,150 | 1965-66 | 26,320 |
| 06-07 | 324,000 | 36-37 | 100,100 | 66-67 | 140,000 |
| 07-08 | 46,500 | 37-38 | 286,000 | 67-68 | 41,510 |
| 08-09 | 239,000 | 38-39 | 15,220 | 68-69 | 110,100 |
| 09-10 | 84,200 | 39-40 | 92,580 | 69-70 | 58,120 |
| 1910-11 | 272,000 | 1940-41 | 200,000 | 1970-71 | 42,300 |
| 11-12 | 16,500 | 41-42 | 128,100 | | |
| 12-13 | 6,550 | 42-43 | 79,490 | | |
| 13-14 | 179,000 | 43-44 | 35,010 | | |
| 14-15 | 182,000 | 44-45 | 48,430 | | |
| 1915-16 | 233,000 | 1945-46 | 15,740 | | |
| 16-17 | 86,000 | 46-47 | 2,080 | | |
| 17-18 | 12,600 | 47-48 | 899 | | |
| 18-19 | 107,000 | 48-49 | 5,610 | | |
| 19-20 | 8,250 | 49-50 | 8,680 | | |

Table 6 (continued)

Patterson Creek Near Union City

| Year | Amount | Year | Amount | Year | Amount |
|---|---|---|---|---|---|
| 1958-59 | 10,410 | 1963-64 | 4,240 | 1967-68 | 6,020 |
| 59-60 | 7,290 | 64-65 | 60,960 | 68-69 | 98,820 |
| 60-61 | 7,290 | 65-66 | 7,160 | 69-70 | 40,620 |
| 61-62 | 22,640 | 66-67 | 118,200 | 70-71 | 31,680 |
| 62-63 | 42,800 | | | | |

Alameda Creek Near Decoto

| Year | Amount | Year | Amount | Year | Amount |
|---|---|---|---|---|---|
| 1916-17 | 74,000 | 1917-18 | 7,200 | 1918-19 | 91,400 |

Alameda Creek at Union City

| Year | Amount | Year | Amount | Year | Amount |
|---|---|---|---|---|---|
| 1958-59 | 140 | 1963-64 | 99 | 1967-68 | 32 |
| 59-60 | 614 | 64-65 | 5,590 | 68-69 | 0.6 |
| 60-61 | 0 | 65-66 | 560 | 69-70 | 160 |
| 61-62 | 1,300 | 66-67 | 266 | 70-71 | 723 |
| 62-63 | 3,860 | | | | |

Dry Creek at Union City

| Year | Amount | Year | Amount | Year | Amount |
|---|---|---|---|---|---|
| 1916-17 | 957 | 1961-62 | 1,060 | 1966-67 | 2,930 |
| 17-18 | 61 | 62-63 | 1,970 | 67-68 | 612 |
| 18-19 | 1,330 | 63-64 | 224 | 68-69 | 3,580 |
| 1959-60 | 463 | 64-65 | 1,820 | 69-70 | 1,680 |
| 60-61 | 8 | 65-66 | 323 | 70-71 | 1,580 |

TABLE 7

UNGAGED TRIBUTARY HILLSIDE RUNOFF
(In Acre-Feet)

| Year | Tributary to Node: 1[a] | 2 | 4 | 3[b] | 6 | 8 | 13 | 14 |
|---|---|---|---|---|---|---|---|---|
| 1961-62 | 300 | 80 | 15 | 140 | 45 | 375 | 240 | 480 |
| 62-63 | 2,610 | 245 | 40 | 445 | 140 | 1,170 | 755 | 1,510 |
| 63-64 | 310 | 30 | 5 | 50 | 15 | 135 | 90 | 175 |
| 64-65 | 565 | 125 | 20 | 232 | 70 | 610 | 395 | 785 |
| 1965-66 | 600 | 50 | 10 | 90 | 25 | 235 | 155 | 305 |
| 66-67 | 3,880 | 365 | 60 | 662 | 200 | 1,745 | 1,130 | 2,245 |
| 67-68 | 650 | 70 | 10 | 123 | 35 | 320 | 210 | 420 |
| 68-69 | 1,780 | 285 | 45 | 520 | 155 | 1,370 | 885 | 1,765 |
| 69-70 | 80 | 70 | 10 | 130 | 40 | 335 | 215 | 435 |
| 1970-71 | 80 | 175 | 30 | 315 | 95 | 835 | 540 | 1,075 |

a - Does not include gaged flow of Dry Creek at Union City (Table 6).
b - Does not include gaged flow of Alameda Creek near Niles (Table 6).

TABLE 8

LAND USE, FREMONT MODEL AREA
(In Acres)

Model Area - 108,040 Acres

| Year | Irrigated Agriculture | Municipal and Industrial | Salt Ponds | Water Surface* | Dry Farm and Native |
|---|---|---|---|---|---|
| 1961-62 | 12,850 | 8,420 | 24,200 | 25,430 | 37,140 |
| 62-63 | 11,990 | 10,010 | 24,200 | 25,430 | 36,410 |
| 63-64 | 11,520 | 10,710 | 24,200 | 25,430 | 36,180 |
| 64-65 | 11,100 | 11,200 | 24,200 | 25,430 | 36,110 |
| 1965-66 | 10,670 | 11,700 | 24,200 | 25,430 | 36,040 |
| 66-67 | 10,240 | 12,200 | 24,200 | 25,430 | 35,970 |
| 67-68 | 9,810 | 12,690 | 24,200 | 25,430 | 35,910 |
| 68-69 | 9,390 | 13,190 | 24,200 | 25,430 | 35,830 |
| 69-70 | 6,700 | 14,610 | 24,200 | 25,430 | 37,100 |

*Includes San Francisco Bay

TABLE 9

IMPORTED WATER
(In 1,000 Acre-Feet)

| Water Year | Source: City of San Francisco: Bunting Pit (1) | Alameda Creek (2) | Hetch Hetchy (3) | State of California (4) | Total For Recharge (5)=(1)+(2)+(4) | Total For All Uses (6)=(3)+(5) |
|---|---|---|---|---|---|---|
| 1961-62 | - 2.33* - | | 1.17 | 5.47 | 7.80 | 8.97 |
| 62-63 | 1.12 | 1.05 | 0.82 | 11.20 | 13.37 | 14.19 |
| 63-64 | 1.34 | 0.46 | 1.74 | 18.23 | 20.03 | 21.77 |
| 64-65 | 5.31 | 0.41 | 1.80 | 16.25 | 21.97 | 23.77 |
| 1965-66 | 2.57 | 0.53 | 3.10 | 15.04 | 18.14 | 21.24 |
| 66-67 | 5.55 | 1.60 | 5.70 | 8.21 | 15.36 | 21.06 |
| 67-68 | 4.04 | 0.38 | 3.46 | 28.60 | 33.02 | 36.48 |
| 68-69 | 5.56 | 1.17 | 3.86 | 13.41 | 20.14 | 24.00 |
| 69-70 | 3.64 | 1.03 | 3.59 | 14.56 | 19.23 | 22.82 |
| 1970-71 | 3.18 | 2.17 | 5.57 | 10.13 | 15.48 | 21.05 |

*Sum of amounts for Bunting Pit and Alameda Creek.

## City of San Francisco

Through its Hetch Hetchy Aqueduct, the City of San Francisco delivers treated water to the cities of Hayward and Milpitas and to the Alameda County Water District. All of this supply is served to customers of the local water systems, and is accounted for in the inventory as recharge of applied water. Alameda County Water District also receives small amounts of water from the City of San Francisco's Sunol Aqueduct. This water is delivered to the Bunting Pits (located on the south side of Alameda Creek west of Mission Boulevard) for recharge and to other users along Alameda Creek.

## State of California

The South Bay Aqueduct of the California State Water Project has been a source of recharge water to the Fremont area since 1962, when the first section to be completed was put into operation. Water was released from the aqueduct at the Altamont Turnout and flowed through the Livermore Valley to Niles until 1965, when the remainder of the aqueduct was completed. Since then water has been released to Alameda Creek at the Vallecitos Turnout.

The ground water is recharged by water from the South Bay Aqueduct, released to flow in Alameda Creek, and then diverted into adjacent gravel pits near Niles.

## Ground Water Inventory

A schematic representation of the hydrologic system is shown on Figure 11. The reference, or free body, used in the ground water inventory is the ground water in storage. The inventory is made on an annual basis, and under the assumption that water which percolates below the root zone will reach the ground water mass during the same water year. The inventory can be represented by the simple equation: Supply - Withdrawal = Change in Storage.

Items of supply, or recharge, to the ground water are derived mainly from precipitation, storm runoff, imported water, and pumped ground water. Specifically, the items of supply are:

1. Portion of precipitation percolating to ground water.

2. Portion of storm runoff, or streamflow, including imported water released into Alameda Creek and adjacent gravel pits, percolating to ground water.

3. Portion of applied (delivered) water percolating to ground water. (Applied water included pumped ground water and imported water put directly into water distribution systems.)

4. Subsurface inflow.

5. Water released by compaction of clay beds.

Withdrawals from the ground water consist of ground water pumpage and subsurface flow out of the basin.

Change in storage is the annual volume of ground water gained or lost from storage.

## Direct Recharge of Precipitation and Delivered Water

The disposition of combined amounts of precipitation and applied water to evapo-transpiration, recharge, and runoff are computed for each type of land use. Starting at the beginning of a water year, and on a monthly-accounting basis, from October through April, the monthly amounts of precipitation and applied water are used to satisfy the soil moisture deficiency and potential evapo-transpiration consumptive use. The same process is followed during the summer growing season, but on a lump sum basis. During the growing season the amount of recharge must also be at least 20 percent of the applied water to allow for irrigation when roots had not developed their maximum ability to take moisture. Monthly potential evapo-transpiration rates, moisture holding content of soils, and effective rooting depths for crops are shown on Table 10.

Since records on the amounts of water applied to individual crops are available only for 1972, data concerning annual amounts of applied water for the Northern Santa Clara County study area to the south were used for the Fremont area. As in the Santa Clara study, total irrigation during years before a pump tax was imposed was assumed to be one irrigation greater than in years after the pump tax.

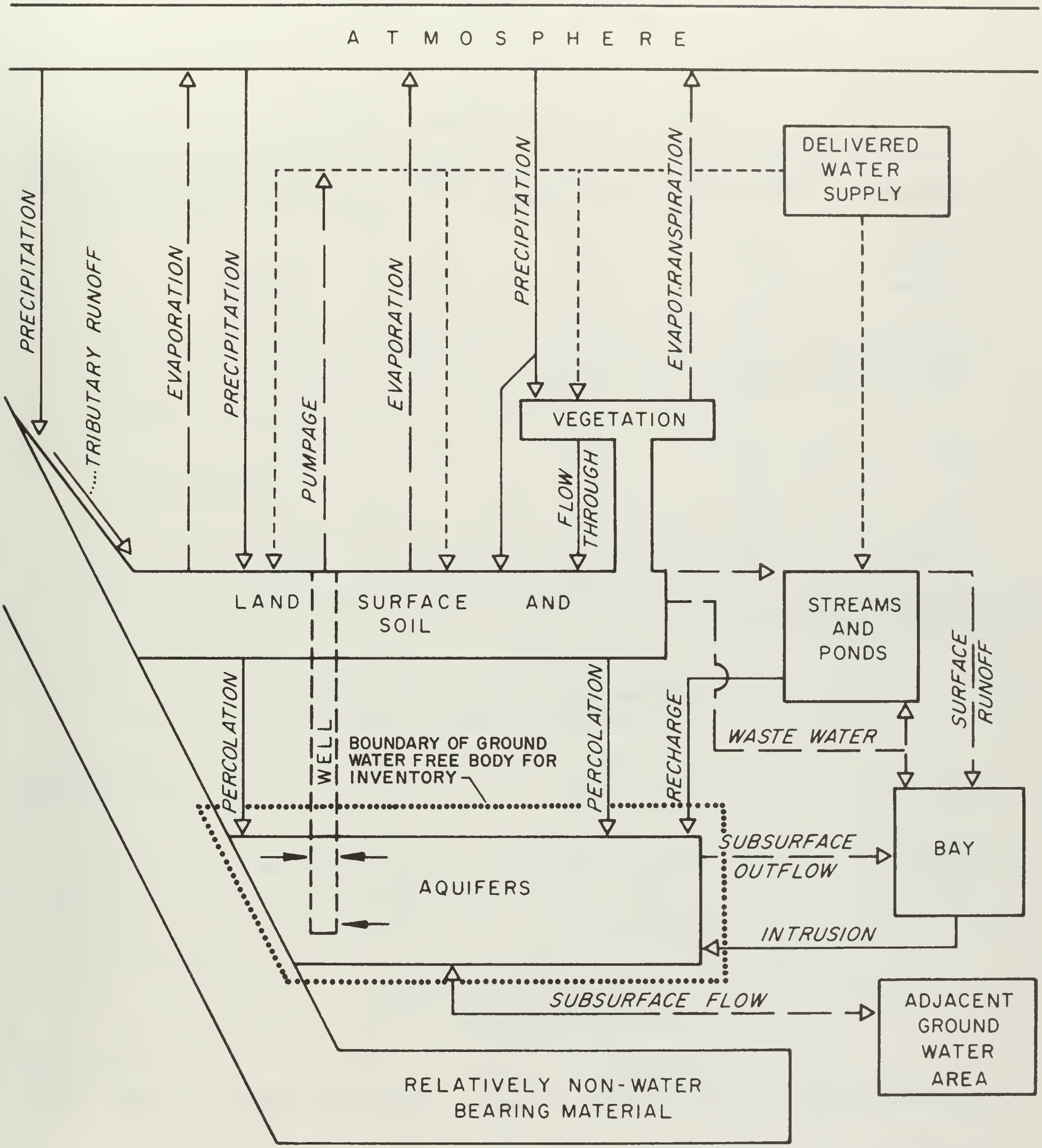



Figure II. HYDROLOGIC SYSTEM (SCHEMATIC)

TABLE 10

AGRICULTURAL WATER USE FACTORS

Monthly Potential Evapo-Transpiration
(In Inches)

| Month | Improved Pasture* | Alfalfa | Sugar Beets | Deciduous Orchard | Nonirrigated Barley |
|---|---|---|---|---|---|
| October | 3.5 | 3.5 | 3.5 | 2.7 | 2.0 |
| November | 1.7 | 1.7 | 1.7 | 1.1 | 1.7 |
| December | 0.9 | 0.9 | 0.9 | 0.9 | 0.9 |
| January | 1.1 | 1.1 | 1.0 | 1.1 | 1.1 |
| February | 1.0 | 1.0 | 1.3 | 1.4 | 1.9 |
| March | 3.1 | 2.9 | - | 2.1 | 3.1 |
| April | 4.6 | 4.1 | - | 3.2 | 3.4 |
| May | 5.7 | 5.1 | 1.7 | 4.6 | 1.2 |
| June | 7.3 | 6.5 | 5.6 | 6.2 | 0.4 |
| July | 7.4 | 6.8 | 7.7 | 6.8 | 0.0 |
| August | 6.5 | 6.2 | 6.6 | 5.8 | 0.0 |
| September | 4.9 | 4.8 | 5.3 | 4.3 | 0.3 |

*Evapo-transpiration of improved pasture considered equivalent to potential evapo-transpiration.

Moisture Holding Content for Soils
(In Inches per Foot of Soil)

| Soil Type | Available Water Content | Soil Type | Available Water Content |
|---|---|---|---|
| Sand | 1.0 | Silty Clay | 1.7 |
| Clay | 1.0 to 1.5 | Silty Clay Loam | 2.0 |
| Clay Loam | 1.4 | Silt Loam | 2.3 |
| Loam | 1.7 | Silt | 2.9 |

Effective Rooting Depth
(In Feet)

| Irrigated Crop | Effective Root Depth | Irrigated Crop | Effective Root Depth |
|---|---|---|---|
| Pasture | 2 | Misc. Truck | 3 |
| Alfalfa | 6 | Tomatoes | 5 |
| Sugar Beets | 5 | Orchard, Mixed | 6 |
| General Field | 4 | Vineyard | 5 |
| Walnuts | 8 | | |

Annual amounts of applied irrigation water varied according to the amount of rainfall occurring in February, March, and April, since rainfall in these months controls the moisture in the soil at the start of the growing season. Annual amounts of water applied to irrigated lands are listed in Table 11. Applied water on urban areas was assumed to be a depth of three feet on the pervious area.

Annual amounts of rainfall becoming local runoff are computed as rainfall on impervious areas less evaporation. Average daily rates of rainfall evaporation are listed in Table 12. For irrigated and native lands, 10 percent is assumed to be impervious. For urban areas, 50 percent is assumed impervious. The depth of runoff is shown on Table 13.

### Depth of Recharge

The maximum depth of recharge shown on Table 13 for each nodal area and year was computed for irrigated agricultural, native, and urban lands east of the salt evaporation ponds. For irrigated agriculture the value was computed for each nodal area based on the crop pattern of 1967.

### Annual Recharge

The annual amounts of direct recharge (from rain and delivered water) are the products of the land use areas and the depth of recharge amount for the specific land use. The amount of recharge actually occurring will be less than this computed amount due to the high percentages of clay present in some portions of the area. To correct for the low permeability of the clay areas, the distance from the apex of the Alameda Creek cone were taken into account. The effect of distance from the apex of the cone is shown in Figure 12. The clay content for each node is shown on Figure 13. Annual amounts of recharge corrected by the recharge factors are listed in Table 14 on page 56.

## Recharge from Streamflow

Streamflow available for recharge is the sum of flows originating in the hills to the west and local runoff from the surface of the study area. Local runoff originating on the valley lands of the study area is that portion of precipitation not consumed or percolating to ground water. On its way to San Francisco Bay or a gaged channel, a portion of this local runoff may percolate. Due to the location of recharge facilities and gaging stations, the analysis of runoff has been divided into analysis of the gaged portion of the study area bounded by Alameda Creek, Dry Creek, and the hills to the northeast, and analysis of runoff in the remaining ungaged study area, less the Bay and the salt ponds.

### Alameda and Dry Creeks Area

In the area bounded by Alameda Creek, Dry Creek, and the hills to the northeast, surface flows available for percolation include those passing the upper gage on Alameda Creek and the Dry Creek gage, tributary ungaged runoff from the hills to the north, and local runoff developed within this area.

TABLE 11

DEPTHS OF APPLIED WATER
(In Feet)*

| Water Year | Deciduous | Pasture | Tomato | Cole | Average |
|---|---|---|---|---|---|
| 1961-62 | 1.20 | 2.40 | 1.95 | 2.40 | 1.89 |
| 62-63 | 1.05 | 1.95 | 1.50 | 1.95 | 1.60 |
| 63-64 | 1.80 | 2.56 | 2.03 | 2.56 | 2.15 |
| 64-65 | 1.20 | 2.03 | 1.65 | 2.03 | 1.72 |
| 1965-66 | 1.80 | 2.56 | 2.03 | 2.56 | 2.15 |
| 66-67 | 1.05 | 1.95 | 1.50 | 1.95 | 1.60 |
| 67-68 | 1.50 | 2.40 | 1.95 | 2.40 | 1.12 |
| 68-69 | 1.20 | 2.03 | 1.65 | 2.03 | 1.72 |
| 69-70 | 1.35 | 2.25 | 1.80 | 2.25 | 1.94 |

*Acre-feet per gross acre with 10 percent of gross area assumed as impervious.

TABLE 12

AVERAGE DAILY EVAPORATION RATES
(In Inches)

| Month | During Storm | After Storm |
|---|---|---|
| October | 0.040 | 0.063 |
| November | 0.024 | 0.038 |
| December | 0.014 | 0.019 |
| January | 0.023 | 0.024 |
| February | 0.037 | 0.077 |
| March | 0.055 | 0.121 |
| April | 0.074 | 0.170 |
| May | 0.081 | 0.191 |
| June | 0.063 | 0.218 |
| July | 0.037 | 0.183 |
| August | 0.073 | 0.171 |
| September | --- | 0.119 |

TABLE 13

DEPTHS OF RECHARGE AND RUNOFF
FROM APPLIED WATER AND PRECIPITATION
(In Feet)

| Water Year | Recharge From: Irrigated Land | Recharge From: Urban Land | Recharge From: Dry Farm Land | Runoff From: Urban Land | Runoff From: Nonurban Land |
|---|---|---|---|---|---|
| 1961-62 | 0.64 | 0.56 | 0.31 | 0.40 | 0.10 |
| 62-63 | 0.64 | 0.44 | 0.31 | 0.56 | 0.14 |
| 63-64 | 0.58 | 0.38 | 0.13 | 0.25 | 0.06 |
| 64-65 | 0.61 | 0.42 | 0.30 | 0.44 | 0.11 |
| 1965-66 | 0.65 | 0.40 | 0.24 | 0.34 | 0.08 |
| 66-67 | 0.81 | 0.56 | 0.67 | 0.65 | 0.16 |
| 67-68 | 0.77 | 0.22 | 0.09 | 0.34 | 0.08 |
| 68-69 | 0.89 | 0.62 | 0.74 | 0.61 | 0.15 |
| 69-70 | 0.59 | 0.26 | 0.28 | 0.38 | 0.09 |

A portion of the flow in Alameda Creek is diverted into percolation pits by the Alameda County Water District. The only known surface diversions during the study period are those made by the District. During the last part of the study period, pumpage by gravel pit operators to control water levels in the pits was discharged to Alameda Creek.

Recharge in the Alameda Creek-Dry Creek area is the total runoff available less outflow. The total runoff is the sum of flows in Dry Creek and Alameda Creek at the upstream boundary of the study area, plus local runoff and stream discharges produced within the area. The method of determining the amount of local runoff is described in the section on determining runoff in the remainder of the study area. Recharge from runoff in Alameda Creek, as shown on Table 14, contains releases from the South Bay Aqueduct of the State Water Project, and is computed on the basis of flows measured at Niles gage and Dry Creek gage. The amounts of recharge from runoff shown in Table 14 include recharge in the total area, including the pits. The amounts of South Bay Aqueduct water purchased by the Alameda County Water District are shown in Table 9.

### Remainder of Study Area

The ungaged tributary hillside runoff and the runoff from precipitation are available for percolation on their way to the Bay. Local runoff is computed from land use in Table 5 and depth of runoff in Table 13. The ability of streamflow to become recharge to the ground water is regulated by the pervious areas of the channels conveying the water, the length of time flow

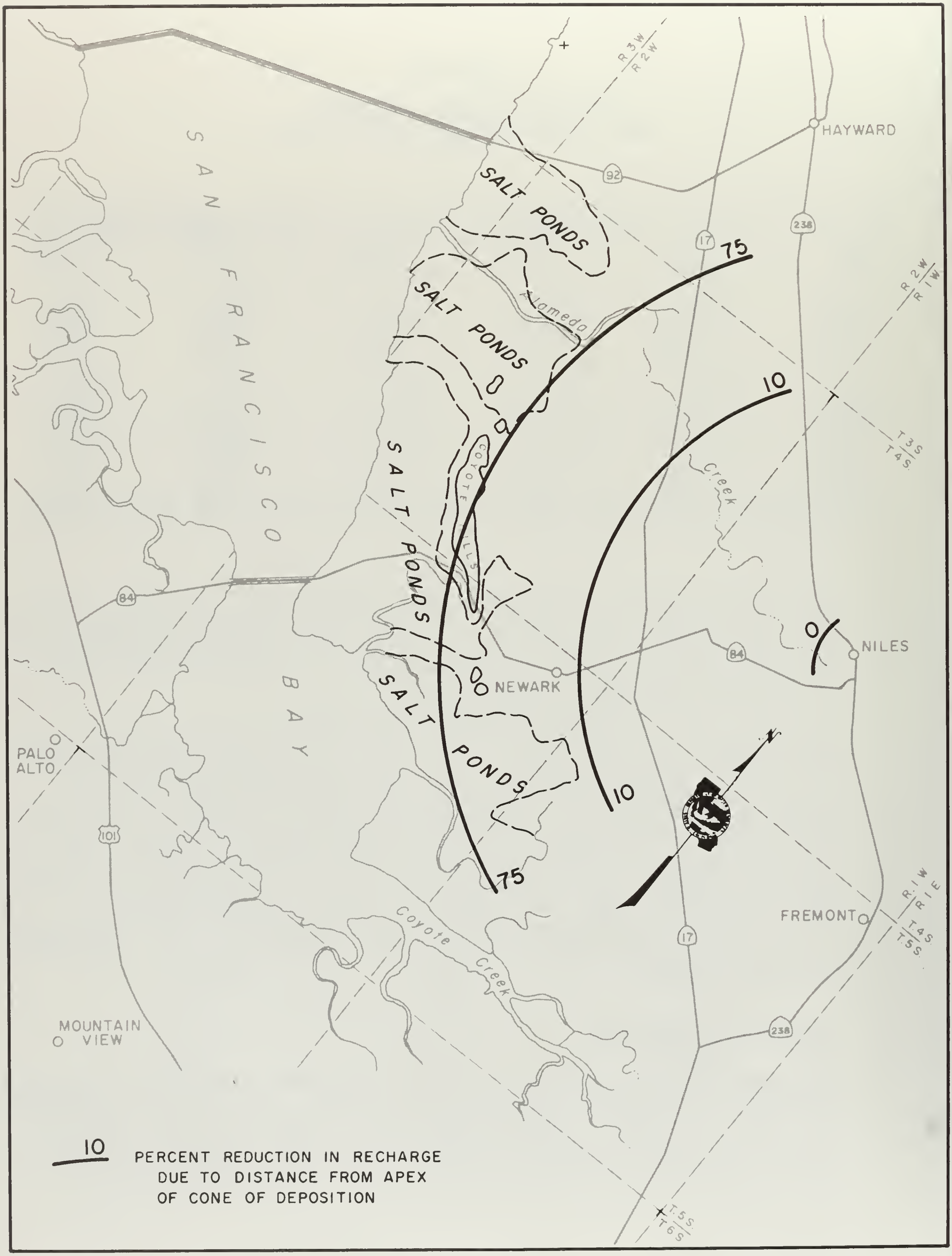



Figure 12. RELATIVE RECHARGE CAPABILITY

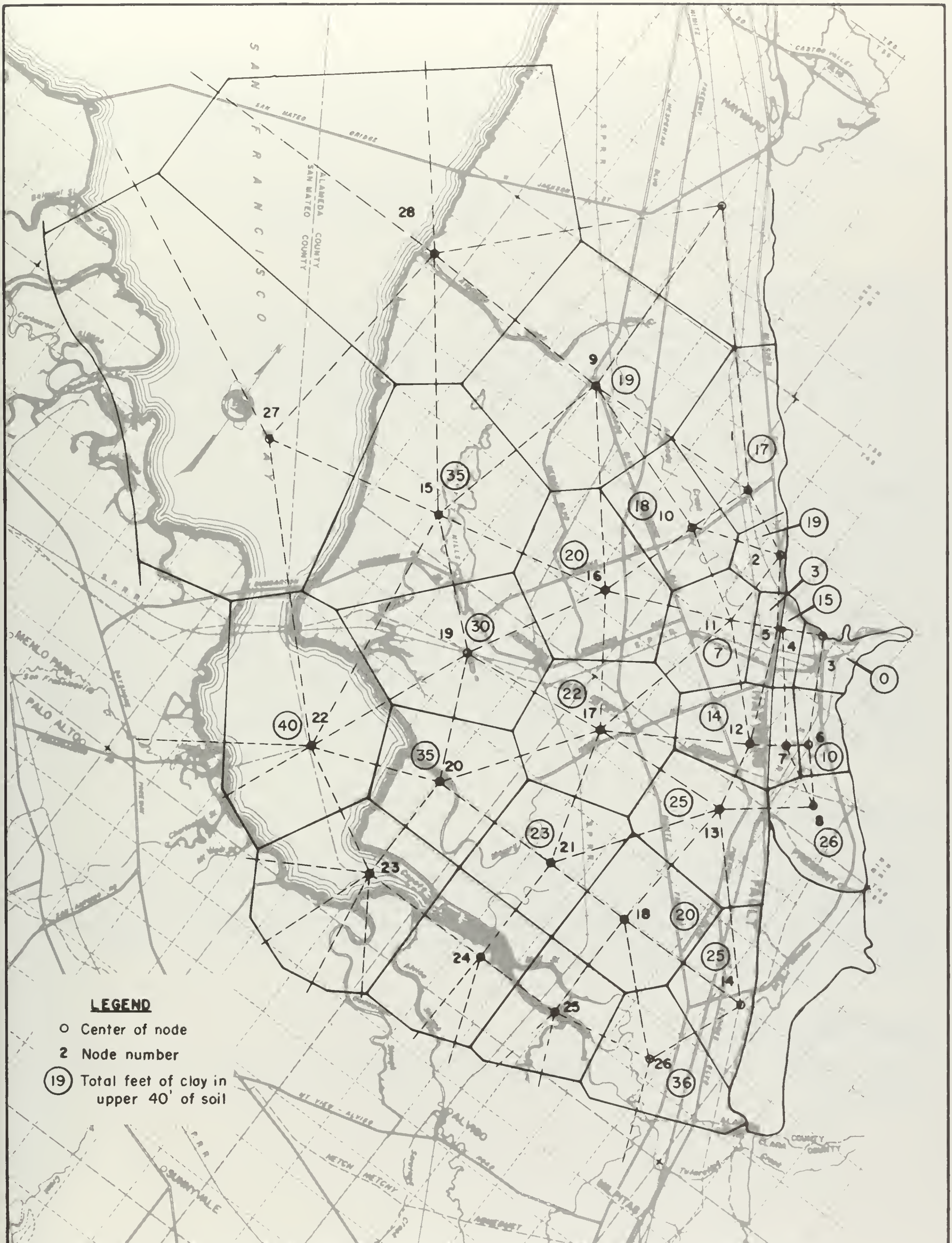



Figure 13. CLAY IN UPPER SOIL STRATA

takes place, and the surface and subsurface characteristics of the soil. In the more pervious portion of the area outside of the Alameda-Dry Creek area, percolation of runoff was determined for the sum of the following computations.

40 percent of the flows of 0 to 5,000 acre-feet
30 percent of the flows of 5,001 to 10,000 acre-feet
20 percent of the flows of 10,001 to 15,000 acre-feet

## Subsurface Inflow

The combination of geologic interpretation of subsurface conditions in Node 8 (Figure 9) and the depth of wells in Node 8 indicate that the majority of pumpage in the node is from the Santa Clara Formation underlying the alluvium. To account for this condition, 90 percent of pumpage in Node 8 was estimated to be subsurface inflow.

## Compaction of Clays

Subsidence occurred in the South Bay Area during years prior to 1969. The center of subsidence is south of San Francisco Bay in Santa Clara County. Subsidence is associated with high amounts of pumpage in northern Santa Clara County and most of the water released by compaction of the aquitards is an inflow to aquifers in the Santa Clara County area. Shallow, thin aquifers belonging to the Fremont and Santa Clara areas overlap each other in the Alviso area and deeper aquifers of the two systems probably merge. This situation requires that a portion of the water produced by compaction of clays be assigned to the Fremont area. The annual amount of 500 acre-feet per year determined for the August 1968 report has been used for years, through 1966-67, and 200 acre-feet for 1967-68. Subsidence did not occur after 1968.

## Ground Water Pumpage

Ground water pumpage is made up of pumpage by Alameda County Water District, Citizens Utility Company, individual industries, individual domestics, and individual agricultural users. All except agriculture are based on information collected by Alameda County Water District. Estimates of agricultural pumpage are based on land use in Table 5 and unit applied water in Table 11. Annual amounts of pumpage are listed in Table 4.

## Saline Water Inflow

Annual volumes of saline water entering the ground water system are computed in Chapter IV.

## Annual Inventory

An annual comparison of amounts of inflow to and outflow from the ground water system is shown in Table 14. Inflow is the sum of recharge from rain, applied water and runoff, subsurface flow, and saline intrusion. Outflow is the sum of municipal, industrial, and agricultural pumpage. The net recharge is comparable to the change in the amount of water in storage.

## Change in Storage

The change in storage is computed as the product of annual change in water levels in the unconfined ground water area and the specific yield of materials in the zone of change. For this computation clays were given a specific yield value of one percent. Annual amounts of change in storage and the comparison with amounts of net recharge are shown in Table 15. Net recharge is computed as the difference between withdrawals and additions of water to the ground water system, and includes pumpage, recharge from rain, runoff and applied water, subsurface inflow, water from subsidence and sea water intrusion. Change in storage and net recharge are computed independently and should be approximately equal. The overall trends of both computations, as shown by their summation plots on Figure 14, are similar and their differences within reasonable limits.

TABLE 14

GROUND WATER INVENTORY

(In 1,000 Acre-Feet)

| Year | Pumpage: Municipal, Industrial | Pumpage: Agricultural | Recharge From: Rain and Applied Water | Recharge From: Runoff: Alameda and Dry Creek | Recharge From: Runoff: Remainder of Area | Subsurface Flow | Compaction | Saline Intrusion | Net Recharge |
|---|---|---|---|---|---|---|---|---|---|
| 1961-62 | 14.5 | 26.3 | 13.5 | 15.9 | 2.2 | 0.7 | 0.5 | 8.6 | 0.6 |
| 1962-63 | 16.6 | 19.8 | 12.6 | 29.4 | 3.5 | 1.4 | 0.5 | 6.6 | 17.6 |
| 1963-64 | 18.5 | 23.6 | 9.5 | 21.9 | 1.4 | 1.4 | 0.5 | 6.8 | - 0.6 |
| 1964-65 | 21.5 | 19.6 | 11.7 | 29.1 | 2.8 | 0.8 | 0.5 | 5.4 | 9.2 |
| 1965-66 | 22.0 | 24.0 | 11.4 | 23.9 | 2.0 | 0.9 | 0.5 | 5.0 | - 2.3 |
| 1966-67 | 19.6 | 17.1 | 18.9 | 38.9 | 4.3 | 0.5 | 0.5 | 3.1 | 29.5 |
| 1967-68 | 26.7 | 20.5 | 7.2 | 44.7 | 2.2 | 0.5 | 0.2 | 1.1 | 8.7 |
| 1968-69 | 34.3 | 16.5 | 20.5 | 35.8 | 4.0 | 0.5 | 0 | 1.7 | 11.7 |
| 1969-70 | 38.2 | 13.1 | 9.2 | 33.8 | 2.4 | 1.4 | 0 | 1.7 | - 2.8 |

TABLE 15

CHANGE IN STORAGE

(In 1,000 Acre-Feet)

| Year | Change in Storage (1) | Net Recharge (2) | Accumulated: Change in Storage (3) | Accumulated: Net Recharge (4) | Accumulated: Difference (5)=(3)-(4) |
|---|---|---|---|---|---|
| 1961-62 | - 4.3 | 0.6 | - 4.3 | 0.6 | - 4.9 |
| 1962-63 | 7.1 | 17.6 | 2.8 | 18.2 | -15.5 |
| 1963-64 | 8.8 | - 0.6 | 11.6 | 17.6 | - 6.0 |
| 1964-65 | 6.6 | 9.2 | 18.2 | 26.8 | - 8.6 |
| 1965-66 | 8.0 | - 2.3 | 26.2 | 24.5 | 1.7 |
| 1966-67 | 20.9 | 29.5 | 47.1 | 54.0 | - 6.9 |
| 1967-68 | 12.5 | 8.7 | 59.6 | 62.7 | - 3.1 |
| 1968-69 | 16.7 | 11.7 | 76.3 | 74.4 | 1.9 |
| 1969-70 | - 6.4 | - 2.8 | 69.9 | 71.6 | - 1.7 |
| 1970-71 | - 5.1 | | 64.8 | | |

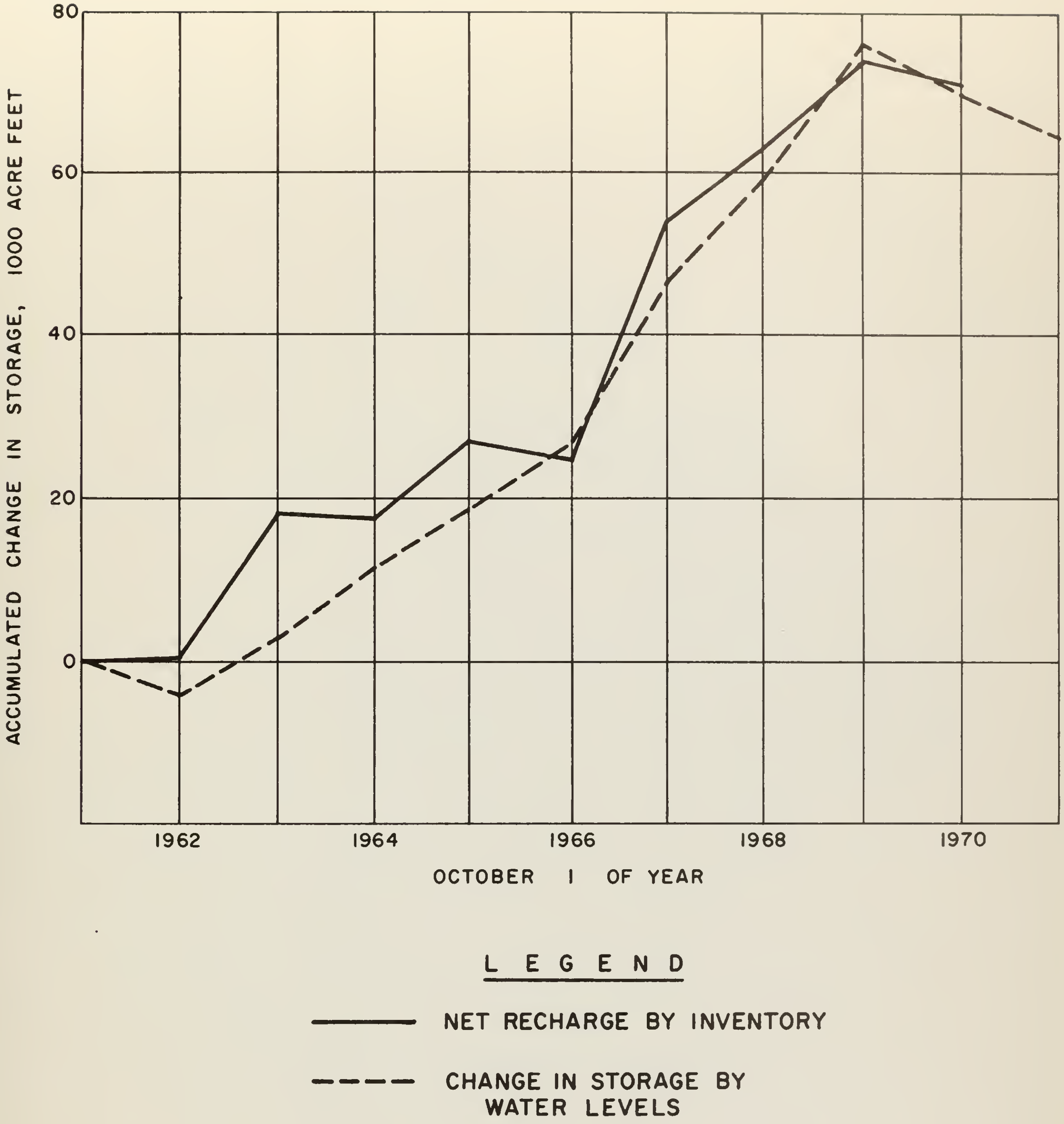
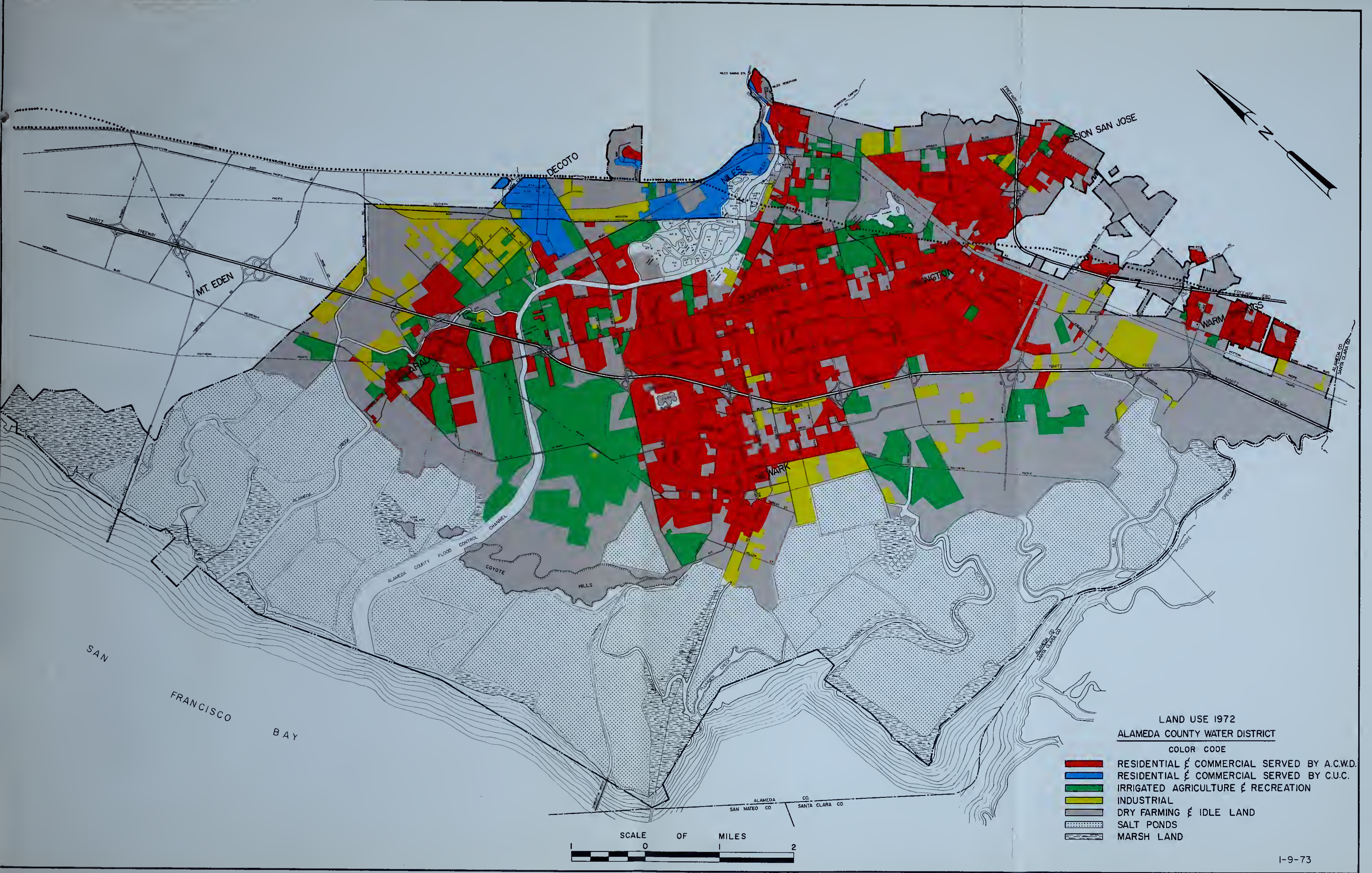



Figure 14. ACCUMULATED CHANGE IN STORAGE


LAND USE 1972
ALAMEDA COUNTY WATER DISTRICT
COLOR CODE
RESIDENTIAL & COMMERCIAL SERVED BY A.C.W.D.
RESIDENTIAL & COMMERCIAL SERVED BY C.U.C.
IRRIGATED AGRICULTURE & RECREATION
INDUSTRIAL
DRY FARMING & IDLE LAND
SALT PONDS
MARSH LAND
SCALE OF MILES
1 0 1 2
1-9-73
N
DECOTO
NILES
MISSION SAN JOSE
MT. EDEN
WARM SPRINGS
SAN FRANCISCO BAY
COYOTE HILLS
ALAMEDA COUNTY FLOOD CONTROL CHANNEL
NIMITZ FREEWAY
FREEWAY 680
ALAMEDA CO.
SANTA CLARA CO.
SAN MATEO CO.